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16. Abstract <p>The primary objective of this research was to test in the field a new method for installing break-away slip-base connections. The new method was developed in the laboratory in a previous phase of the research, and it is based on the utilization of Belleville spring washers. Stacks of spring washers, which come pre-wrapped, are installed on the bolts just as any ordinary washers. The bolts are torqued, and a block of filler gages measures the deflection of the stack of spring washers which is proportional to the tension in the bolt.</p> <p>Seven signs were selected along Central and South Florida highways. At each sign, one of the posts was equipped with bolts with spring washers, while the other post remained connected with bolts with conventional flat washers. At each sign one of the bolt with spring washers and one of the bolts with flat washers were instrumented with strain gages. The variations of tension in these bolts were monitored over a period of one year by measuring the tension of the different bolts once a week.</p> <p>The measurements showed that, at the time of installation, the new method was significantly more effective in ensuring the proper tension in the bolts. Similarly, over the long term, the bolts installed with spring washers maintained more effectively the tension in the bolt, without any loosening of the bolt. On the contrary, several bolts installed with flat washers exhibited a downward trend in the bolt tension.</p> <p>The effectiveness of the break-away connection with spring washers was also demonstrated during a car accident. A car hit a sign post equipped with spring washers, near the Sebastian Inlet. The break-away functioned perfectly and the post separated from the base.</p>			
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EXECUTIVE SUMMARY

The primary objective of this research was to test in the field a new method for installing break-away slip-base connections. The new method was developed in the laboratory in a previous phase of the research, and it is based on the utilization of Belleville spring washers. Stacks of spring washers, which come pre-wrapped, are installed on the bolts just as any ordinary washers. The bolts are torqued, and a block of filler gages measures the deflection of the stack of spring washers which is proportional to the tension in the bolt.

Seven signs were selected along Central and South Florida highways. At each sign, one of the posts was equipped with bolts with spring washers, while the other post remained connected with bolts with conventional flat washers. At each sign one of the bolt with spring washers and one of the bolts with flat washers were instrumented with strain gages. The variations of tension in these bolts were monitored over a period of one year by measuring the tension of the different bolts once a week.

The measurements showed that, at the time of installation, the new method was significantly more effective in ensuring the proper tension in the bolts. Similarly, over the long term, the bolts installed with spring washers maintained more effectively the tension in the bolt, without any loosening of the bolt. On the contrary, several bolts installed with flat washers exhibited a downward trend in the bolt tension.

The effectiveness of the break-away connection with spring washers was also demonstrated during a car accident. A car hit a sign post equipped with spring washers, near the Sebastian Inlet. The break-away functioned perfectly and the post separated from the base.

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the U.S. Department of Transportation.

This report was prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.

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INTRODUCTION

For the efficient control of traffic on highways it is necessary to provide large directional signs. These signs require massive fixed supports which, when located near the roadway, constitute a hazard to the occupants of an errant vehicle. To reduce the hazard, if the signs cannot be located behind a guardrail, the sign supports must be provided with a break-away device.

According to a detailed, mid-60's study of break-away signs performed by Edwards, Hirsch, and Olson at the Texas Transportation Institute, the *bolt tension is the single most critical factor for the safe operation of the break-away sign support*. In fact, the bolts in the slip-base connection must be tightened to a specific tension, in order to satisfy two conflicting requirements: 1) to ensure that the connection will successfully withstand the service loads due mainly to wind, traffic, and temperature effects; and 2) to ensure that the connection will break upon impact from an errant vehicle, thus ensuring the safety of the vehicle's passengers. Consequently, there is a need to accurately and directly measure the tension in the bolts, when the break-away system is installed.

Equally important, is a need to ensure that the tension in the bolts will remain within an acceptable range throughout the service life of the system. Even if the bolts were correctly installed with the proper tension, the bolts could still loosen over time. This arises from the fact that highway signs are subjected to a variety of dynamic loads including the vibrations induced by traffic, and the effect of wind induced vortex shedding. These vibrations are transmitted to the supporting structure and can result in a loosening of the base bolts. Temperature changes due to daily and seasonal changes can also cause non-uniform expansion and contraction of the break-away assembly introducing residual tension in the bolts. In the case of excessive bolt loosening, the base sign connection could fail during a wind event, result in a hazard and disruptions to highway traffic, and result in injury for the occupants of a vehicle, and costly liability for the responsible jurisdiction. In addition, the losses or damage to traffic signs are costly.

To solve the above problem, a two phase research program on break-away signs was carried on at Florida Tech, with funding from the Florida DOT. Phase I of the program addressed the first need listed above, by developing a new installation procedure for the bolts of the slip-base

connections that will replace the calibrated wrench method currently being used. The new installation procedure determines the tension in the bolt by measuring the deflection of a stack of spring washers when installing the bolt.

Phase I of the research program also included laboratory tests on the effect of vibration and temperature variations on the loosening of the bolts in the break-away. It was shown in the laboratory that the spring washers substantially reduced the loosening of the bolts.

Phase II of the research program intended to verify, in the field, the results developed in the laboratory during Phase I. The objectives of Phase II were the following:

- To verify the long-term behavior of the Belleville spring washers, specifically their capacity to maintain the bolt tension within the acceptable range.
- To compare the behavior of the sign post break-away base installed with spring washers with the behavior of the sign post break-away base installed with regular flat washers.
- To determine the longevity of the galvanized and stainless steel spring washers in the open field Florida environment.

FIELD TESTS SET-UP

Instrumentation of Bolts

- Two bolts were used: 3/4" –A235 bolts with two different lengths of 3" and 3 1/2"; and 7/8" bolts also with lengths of 3" and 3 1/2". The 3" bolts were used with standard washer set-ups while the 3 1/2" bolts were used with the proposed Belleville washer set-ups.
- The bolts were instrumented with two strain gages each. The strain gages were mounted 180 degrees apart in the bolt shank in machined grooves in order to protect the strain gages from contact with the plates and the washers of the break-away connection. The strain gages were instrumented in this fashion so that the average of the two strain readings would cancel any bending effects, which may occur in the bolt shaft.
- • Two holes were drilled symmetrically in the bolt head above the two grooves to let electrical leads pass. Figure 1 shows an example of an instrumented bolt.
- The EA-06-240LZ-120 type of strain gages manufactured by Micro-Measurements Group Inc. was used. The gage resistance in ohms at 24 °C is $120.0 \pm 0.3\%$ and a gage factor at 24°C is $2.055 \pm 0.5\%$.
- To take strain measurements, the gages were connected using a quarter bridge pattern to a P-3500 strain gage indicator which has an accuracy of $\pm 0.1\%$ for a gage factor greater than 1. The strain gage indicator was also manufactured by Micro-Measurements Group Inc.

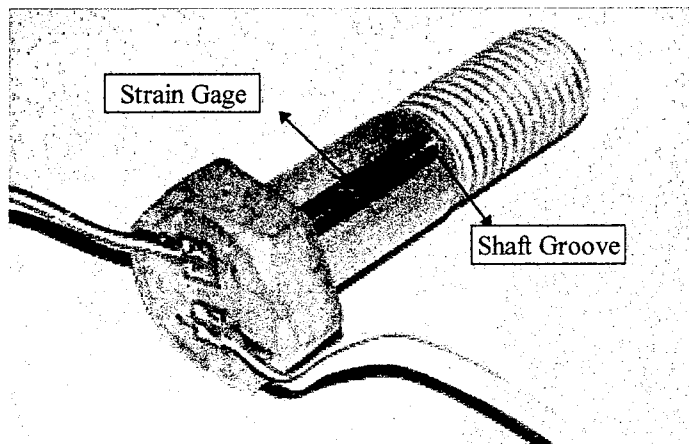
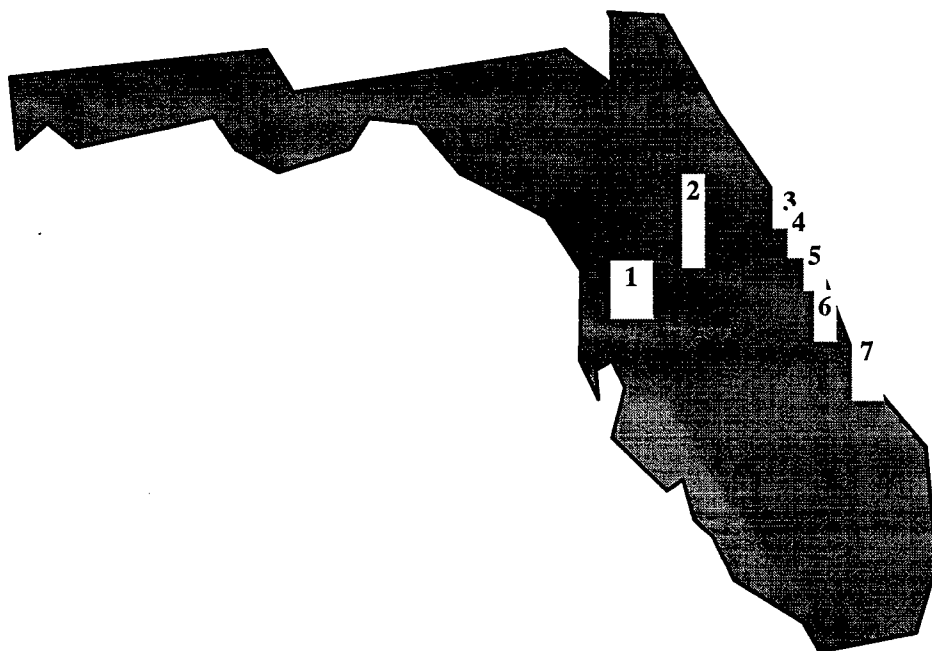



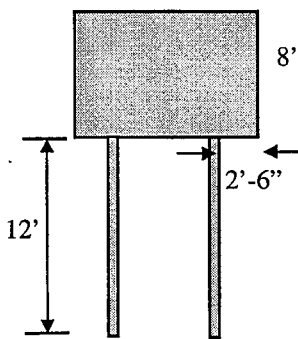
Figure 1 - 3/4" Diameter Instrumented Bolt


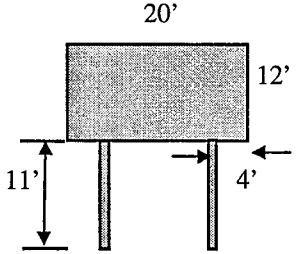

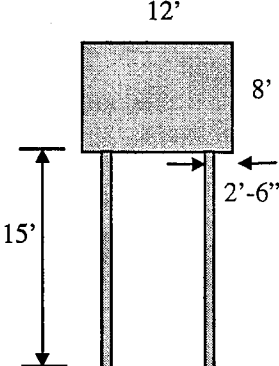

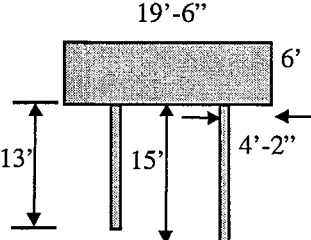

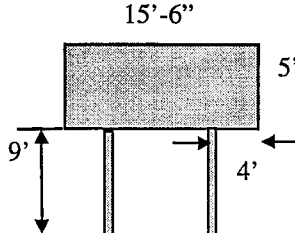

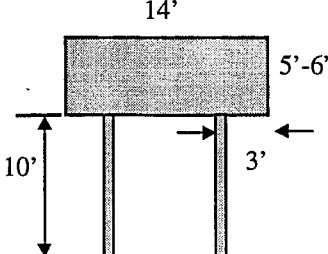
Location and Details of Selected Signs

The first step taken was to select suitable sites throughout Central Florida considering different conditions of wind, traffic and temperature. Seven appropriate sites were identified along I-95, I-4, I-75 and A1A, which are typical of different climate and traffic conditions in central and south Florida. At each site, representative break-away signs were selected for monitoring in coordination with the Florida DOT. Figure 2 and Table 1 show the location and details of the selected sites.

Figure 2 Location of Selected Signs



	<i>Photograph</i>	<i>Dimensions (not to scale)</i>
1. Tampa I-75 northbound just south of the I-75 / I-4 junction. Connected by ¾" bolts. Measurements taken since May 1998.		<div style="text-align: center;"> 12'  </div> <div style="text-align: center;"> Posts: W8X24 </div>

<p>2. Orlando</p> <p>I-4 westbound just north of the Highway 528 / I-4 junction. Connected by ¾" bolts. Measurements taken since May 1998.</p>		 <p>Posts: W8X24</p>
<p>3. Brevard County (2)</p> <p>I-95 northbound second sign north of Exit 74. Connected by ¾" bolts. Measurements taken since May 1998.</p>		 <p>Posts: W8X24</p>
<p>4. Brevard County (1)</p> <p>I-95 northbound first sign north of Exit 74. Connected by 7/8" bolts. Measurements taken since July 1998.</p>		 <p>Posts: W10X45</p>
<p>5. Sebastian Inlet</p> <p>A1A northbound just south of Sebastian Inlet. Connected by ¾" bolts. Measurements taken since May 1998.</p>		 <p>Posts: W8X18</p>
<p>6. Indian River County</p> <p>I-95 southbound just south of mile marker 146. Connected by ¾" bolts. Measurements taken since May 1998.</p>		 <p>Posts: W8X24</p>


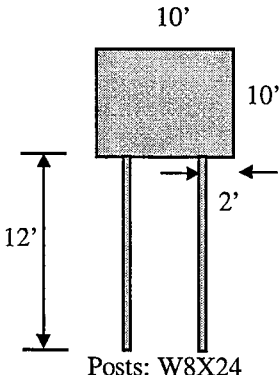
<p>7. Martin County</p> <p>I-95 northbound just north of mile marker 109. Connected by ¾" bolts. Measurements taken since May 1998.</p>		 <p>10'</p> <p>10'</p> <p>12'</p> <p>2'</p> <p>Posts: W8X24</p>
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Table 1: Location and Details of Selected Signs

Installation of Bolts

After the break-away signs were selected, the instrumented bolts were installed. Each sign had two posts, each with four ¾" bolts except for Brevard (1) which has 7/8" bolts. The bolts on one post were installed using the procedure defined in Phase I [1] with the proposed Belleville spring washer set-up, using the 3.5 in long bolts. The Belleville spring washer set-up used included four washers (# AI-1575107), two in series and two in parallel. This set-up requires a deflection of 0.026" to reach FDOT recommended bolt tension. Deflections were measured using filler gages. All material (washers, bolts, and nuts) was provided by FDOT with the exception of the spring washers, which was purchased by the research team. The actual installation was done by the research team with assistance from FDOT crew.

The bolts on the other post were installed following the conventional torquing method and washer set-up, using the 3 in. bolts. The bolts installed using this method were torqued to either 35 ft-lb or 43 ft-lb according to individual FDOT specifications. It can be seen that not all sites use the same torque values. Table 2 shows the specific torques for each of the signs.

Table 2: Recommended Torque Values

<i>Sign</i>	<i>Recommended Torque (ft-lb)</i>
Tampa	43
Orlando	35
Brevard County	43
Sebastian Inlet	43
Indian River County	43
Martin County	43

Each post was equipped with one instrumented bolt so a comparison could be made between the conventional set-up and the proposed set-up. Figures 3 and 4 compare the traditional set-up using conventional flat washer and the proposed set-up using spring washers. The requirement was for the washers to maintain the tension within 2400 lb. to 3600 lb.

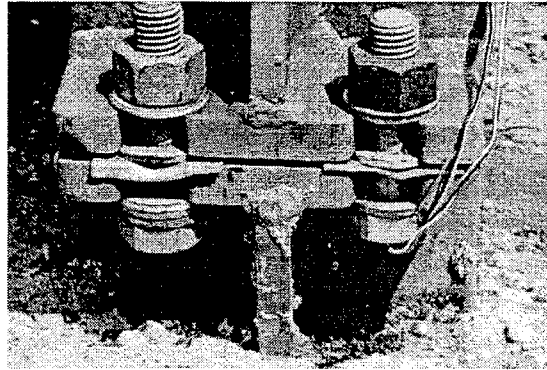


Figure 3 - Traditional Bolt Set-Up with Flat Washers

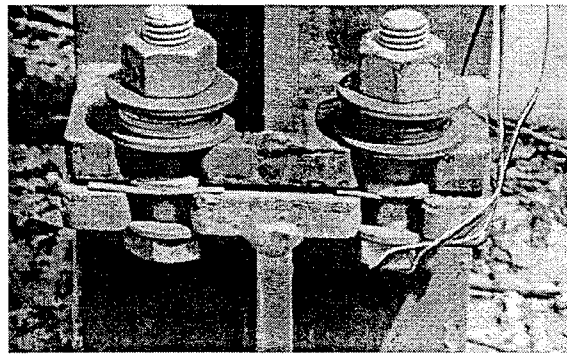


Figure 4 - Proposed Set-Up with Spring Washers

Strain Reading Procedure

1. The signs were checked once a week on average. The Indian River, Martin and Sebastian signs are checked one day while the two Brevard signs along with the Orlando and Tampa signs are checked another week day. Sometimes, the checking could not be carried out because of the weather or because the bolts are not accessible due to flooding.
2. The procedure was as follows:
 - Measured the temperature using a BAT-10 Thermometer made by Physitemp, Inc.
 - Checked for rusting on the spring washers.

- Checked if the strain gages were working (each gage should register a resistance of 120 Ω).
 - Checked the offset readings and adjust the strain indicator accordingly. The offset readings were determined by setting the strain indicator readings to zero when the bolt is in zero tension.
 - Measured the strains on the left and right strain gages.
 - Replaced the wires in a sealed plastic bag and the bag is taped onto the signpost.
3. The measurements were placed in a spreadsheet. The spreadsheet calculated the tension and the eccentricity on each bolt.
 4. If some of the instrumented bolts were damaged, the bolt was removed and replaced with an appropriate regular bolt. The instrumented bolt was brought back, repaired, re-tested in the lab, and re-installed in the field the following week.

Calculation of Tension and Eccentricity

The monitoring of the bolt tensions began as soon as the bolts were installed. The results show how the tensions in the bolts changed since they were installed. Table 3 is an example of spreadsheet results.

Operator	Date	Time	Temp	Strain Reading ($\mu\epsilon$)			Bolt tension		Eccent. (in)
			$^{\circ}\text{C}$	Left	Right	Average	lb.	kN	
			Balance Offset >>	392	59				
S.ON.	7/16/98	9:00	30	284	55	170	2956	13.1	0.074
S.ON.	7/23/98	9:45	32	338	60	199	3470	15.4	0.076
N	8/11/98	1:00	36	237	57	147	2563	11.4	0.067
N	8/26/98	10:30	35	265	92	179	3113	13.8	0.053

Table 3: Brevard (1) Sign, Bolt with Spring Washer (Sample)

The averages of the strain measurements were used to calculate the tensions on each bolt. The eccentricity measures the distance between the bolt tension force and the centroid of the bolt.

The equations used are:

$$Tension = T = E \epsilon_{ave} A$$

Where:

E = Young's modulus measured in the lab. On average, it is equal to 2.9×10^7 psi

A = area of the bolt

$$= \pi \left(\frac{0.75}{2} \right)^2 \quad \text{for the } \frac{3}{4}'' \text{ bolt}$$

$$= \pi \left(\frac{0.875}{2} \right)^2 \quad \text{for the } \frac{7}{8}'' \text{ bolt}$$

$$\text{Eccentricity} = \frac{d}{8} \frac{\epsilon_L - \epsilon_R}{\epsilon_L + \epsilon_R}$$

Where:

d = diameter of the bolt

Figure 5 illustrates the relationship between tension, strain and eccentricity.

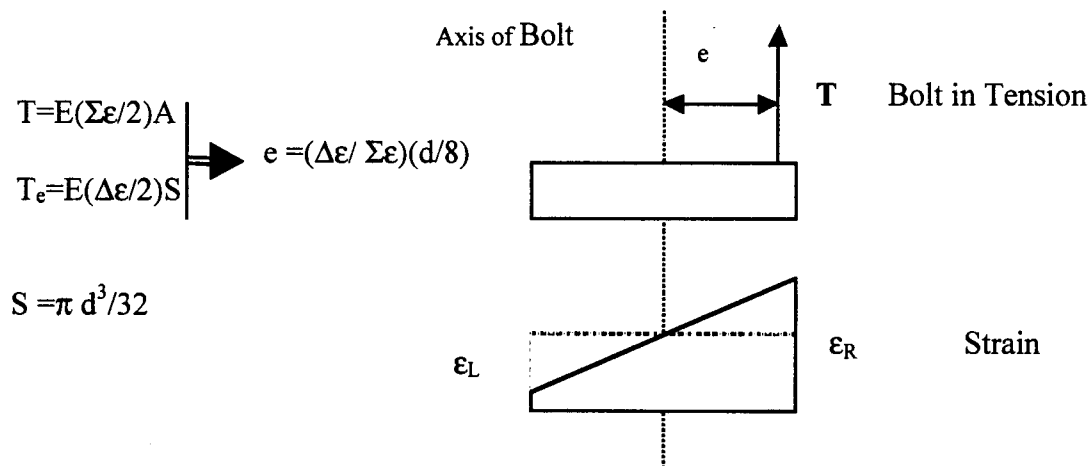


Figure 5 - Bolt Tension Eccentricity

TENSILE TESTS

Prior to installation of the instrumented bolts in the field, tensile tests were performed in the lab, to ensure that the strain gages had been properly installed. The tests were performed following the technique described in the Phase 1 report [1]. In each case, the goal was to verify that the measured modulus of elasticity was close to the theoretical value of 29,000 ksi. Every time a bolt was brought back to the lab for re-instrumenting, a new tensile test was performed prior to re-installing.

Below are the results of the tests for each instrumented bolt. The stress-strain curves are plotted for each bolt. In each figure, the readings from each strain gage are plotted with triangular dots for the left gage and square dots for the right gage. The average values are represented with a solid line. The slope of this line or measured modulus of elasticity is indicated in each plot.

Tampa

Figure 6 shows the result of the tensile test of May 18, 1998 for the short bolt (to be installed with flat washers).

Figure 7 shows the results of the tensile test of May 18, 1998 and the tensile test for the long bolt (to be installed with spring washers) of December 8, 1998.

Orlando

Figures 8 and 9 show the results of the tensile tests of May 16, 1998 and December 1, 1998 for the short bolt.

Brevard (2)

Figures 10, 11, and 12 show the results of the tensile tests of May 16, 1998, November 10, 1998 and January 22, 1999 for the short bolt.

Brevard (1)

Figures 13 and 14 show the results of the tensile test of July 14, 1998 for both bolts and Figure 15 shows the tensile test for the long bolt of November 19, 1998.

Sebastian Inlet

Figures 16 shows the results of the tensile test of December 8, 1998 for the long bolt and Figure 17 shows the results of the tensile test of December 3, 1998 for the short bolt.

Indian River

Figures 18 and 19 show the results of the tensile tests of May 15, 1998 and February 3, 1999 for the long bolt.

Figures 20, 21, and 22 show the results of the tensile test of May 15, 1998, December 8, 1998 and February 2, 1999 for the short bolt.

Martin County

Figure 23 shows the results of the tensile test of December 3, 1998 for the long bolt and Figure 24 shows the results of the tensile test of December 3, 1998 for the short bolt.

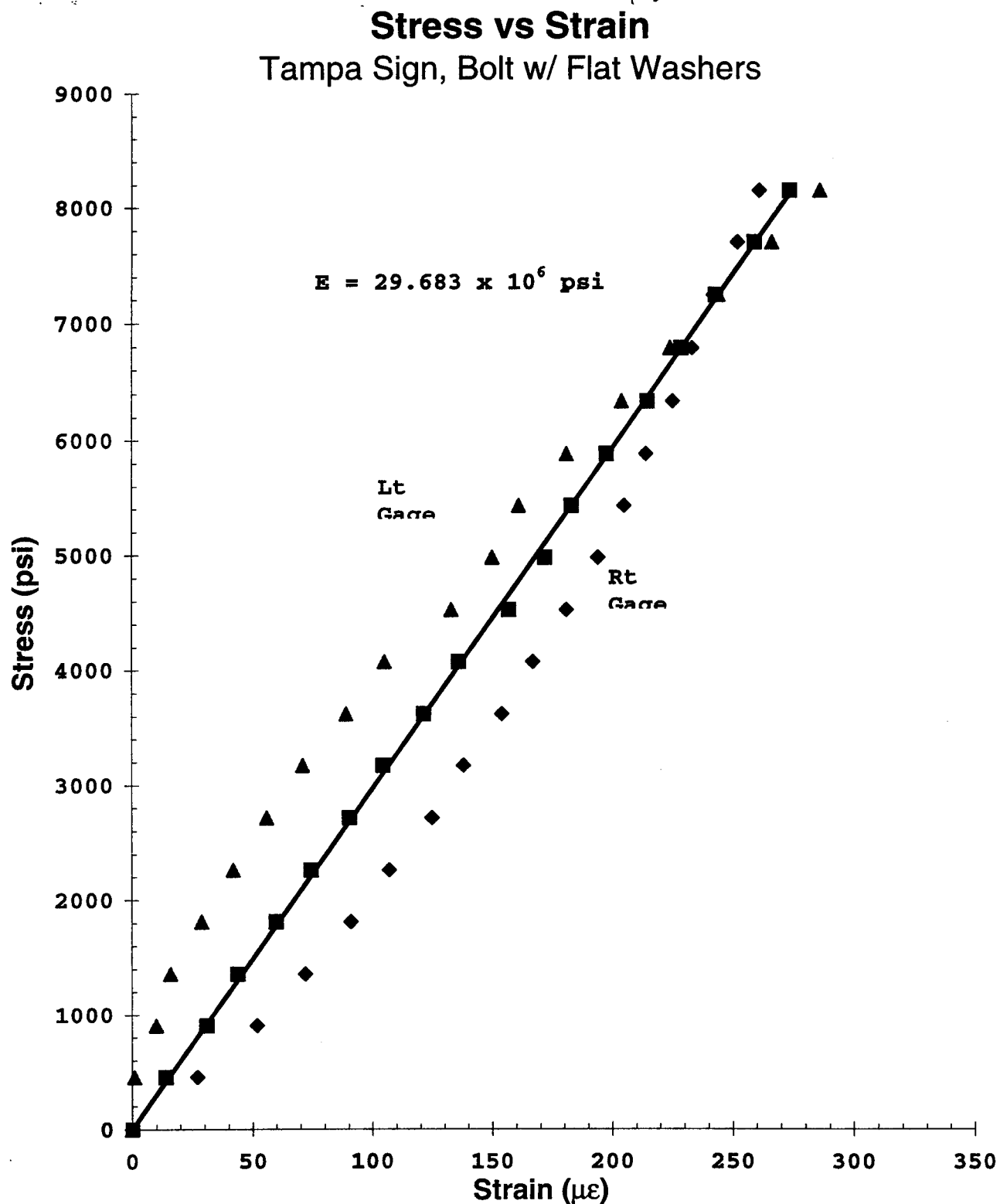


Figure 6 Stress vs Strain, Tampa Sign, Bolt with Flat Washers, May 18, 1998

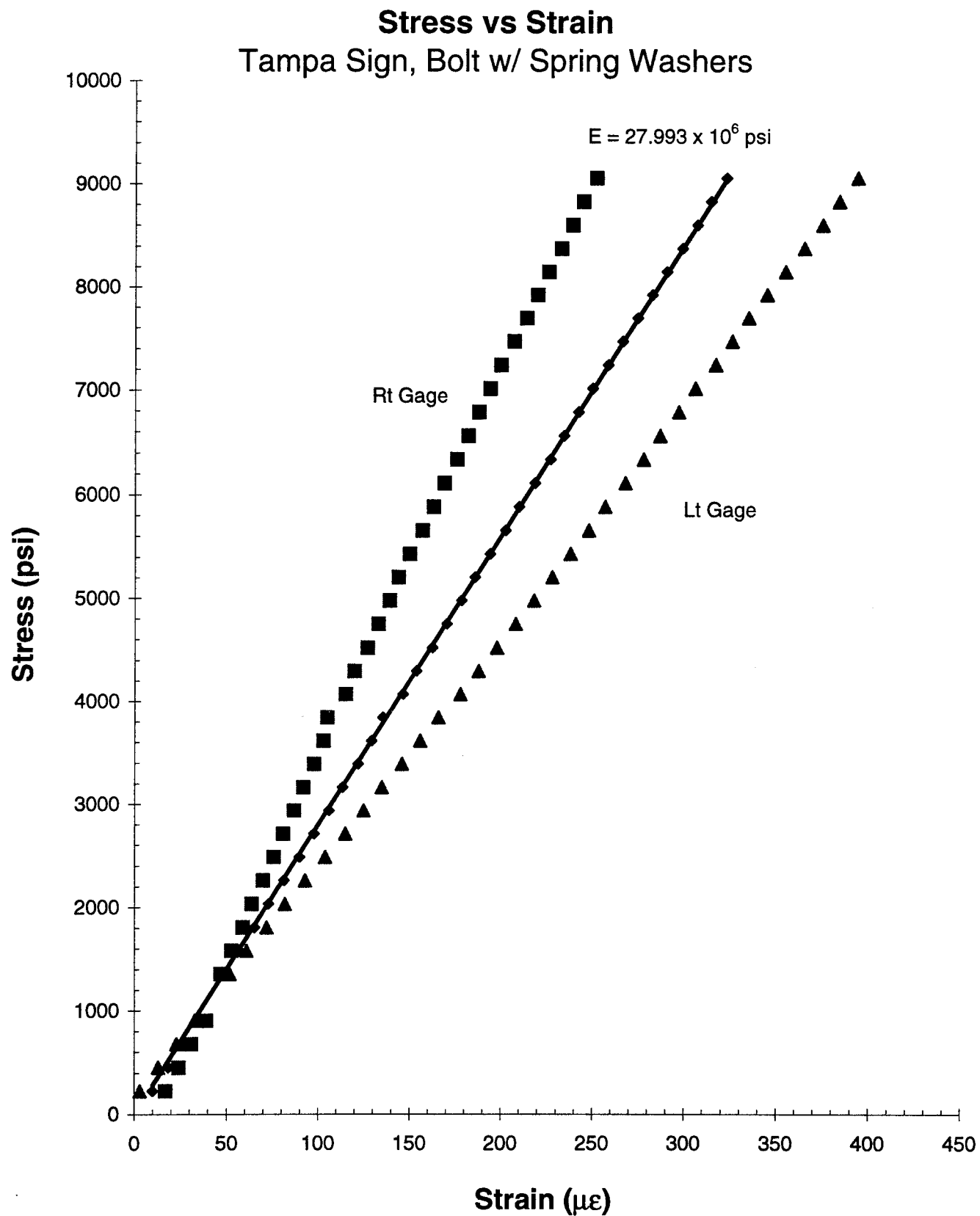


Figure 7 Stress vs Strain, Tampa Sign, Bolt with Spring Washers,
December 8, 1998

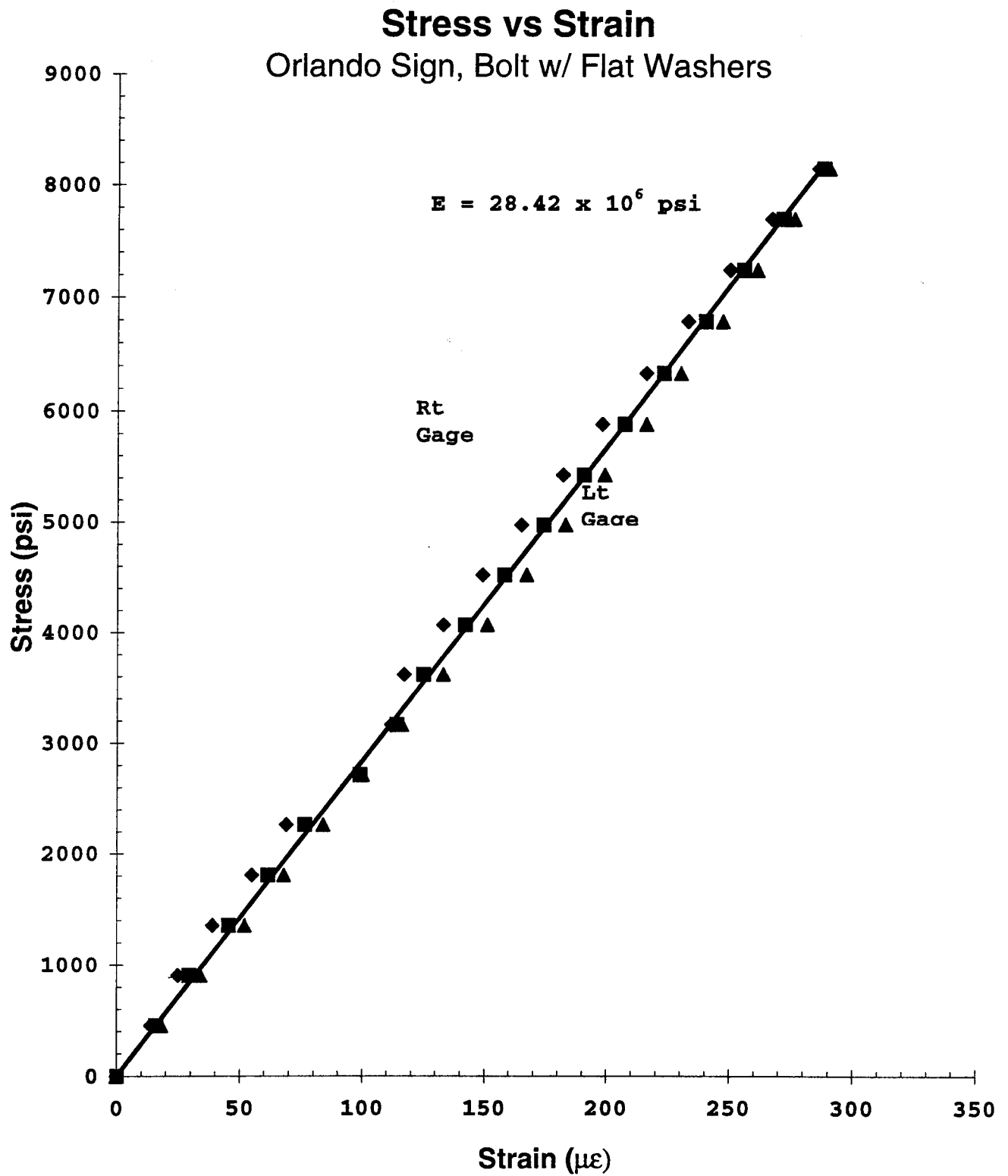


Figure 8 Stress vs Strain, Orlando Sign, Bolt with Flat Washers, May 16, 1998

Stress vs Strain

Orlando Sign, Bolt w/ Flat Washers

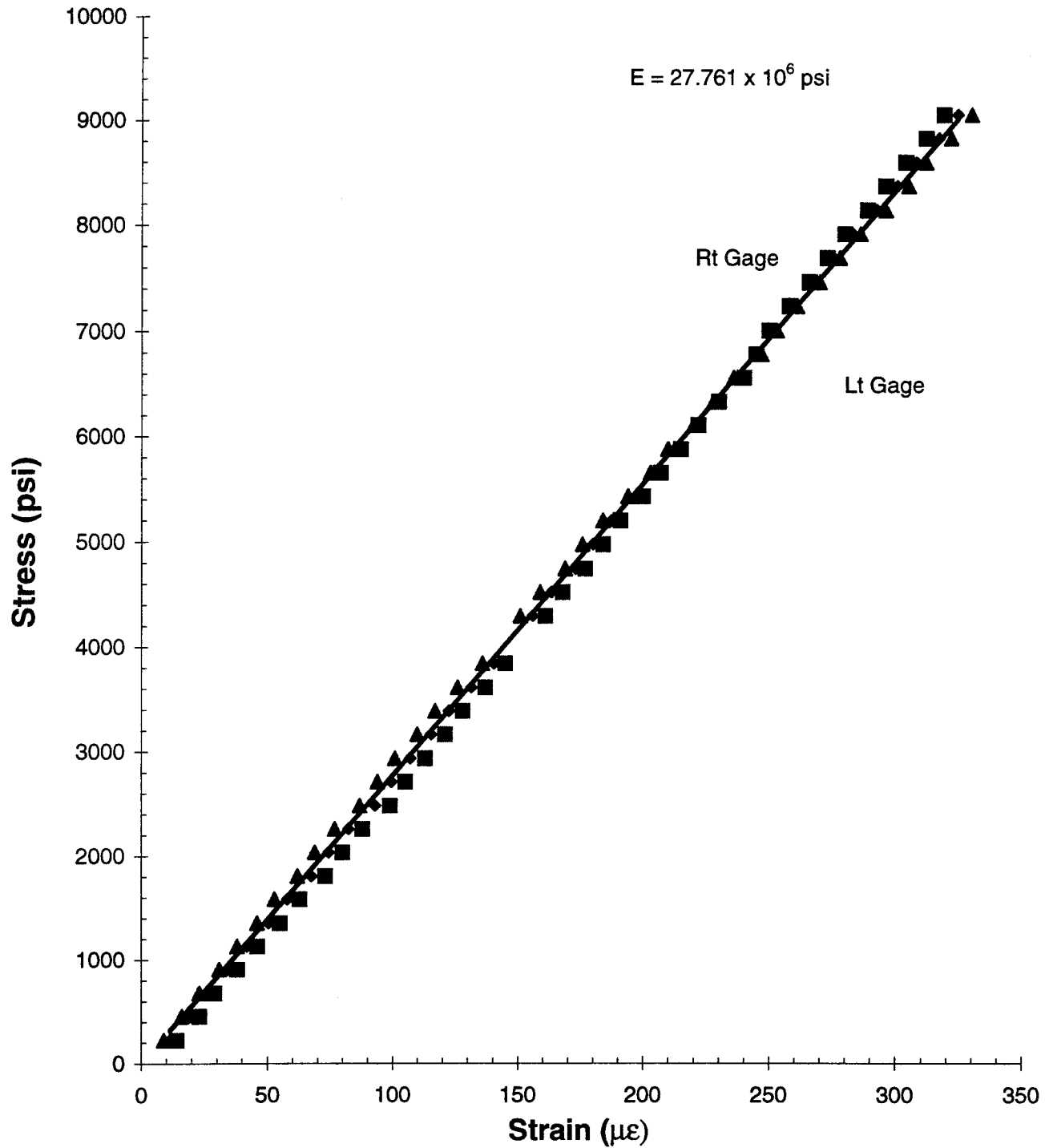


Figure 9 Stress vs Strain, Orlando Sign, Bolt with Flat Washers, December 1, 1998

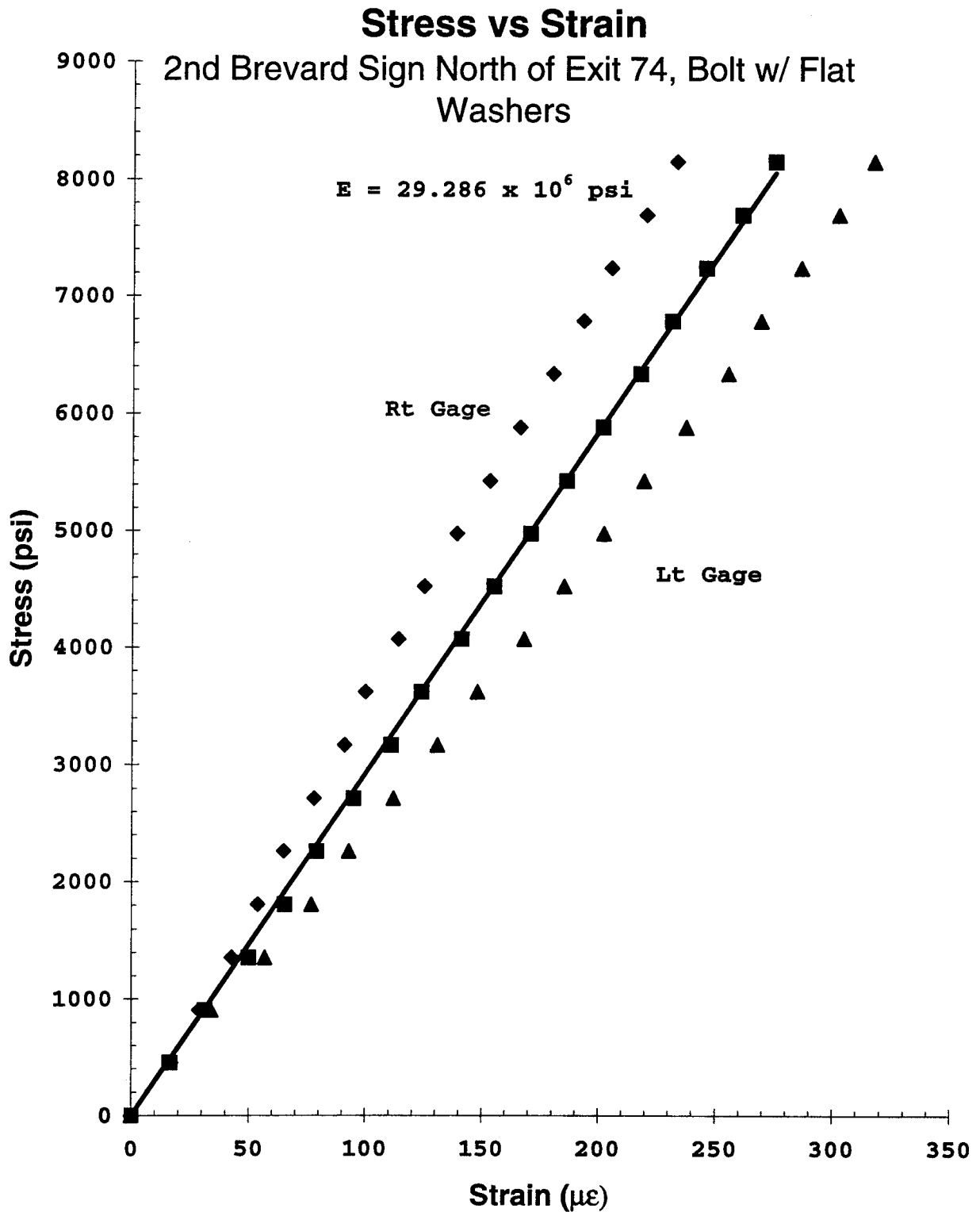


Figure 10 Stress vs Strain, Brevard (2) Sign, Bolt with Flat Washers, May 16, 1998

Stress vs Strain

2nd Brevard Sign North of Exit 74, Bolt w/ Flat Washers

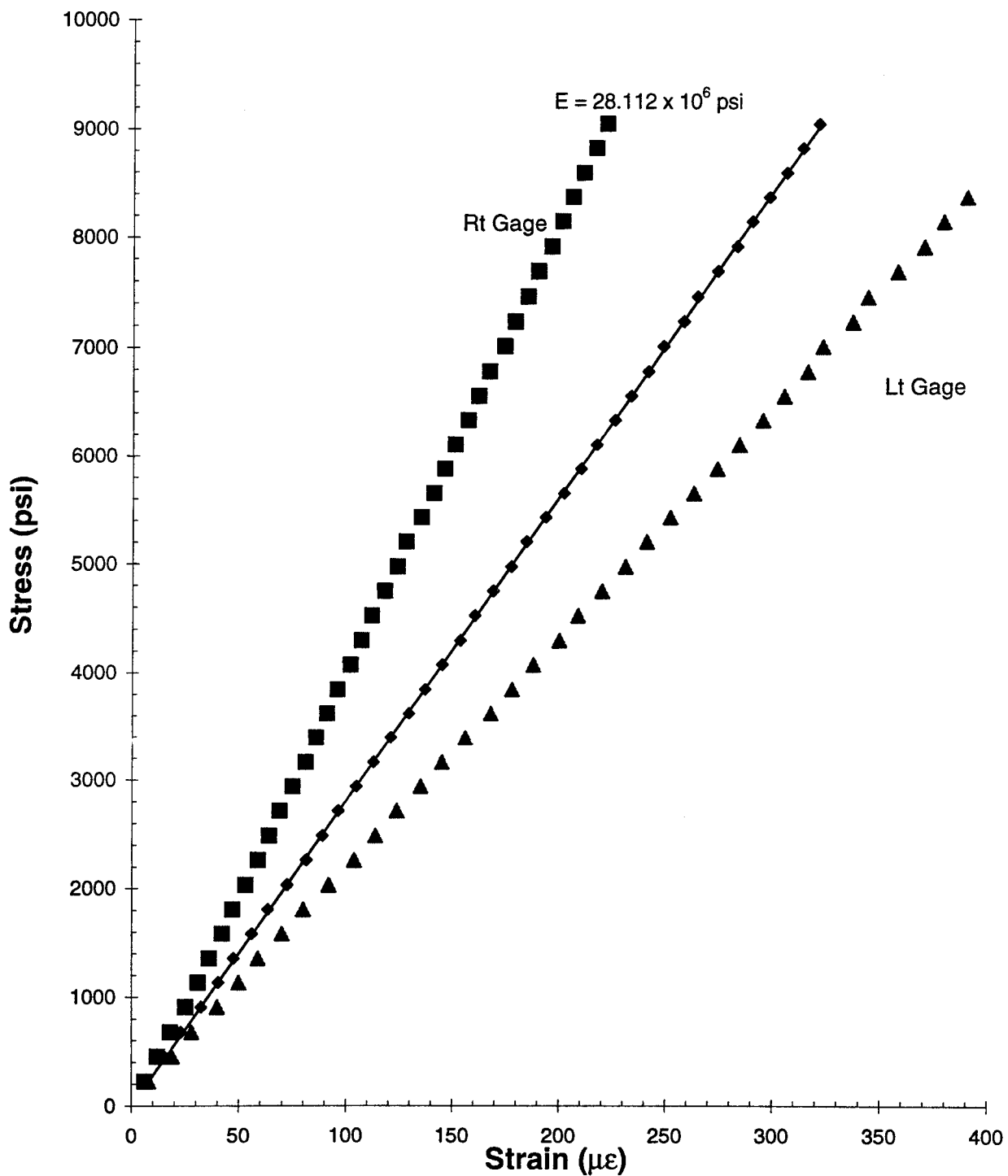


Figure 11 Stress vs Strain, Brevard (2) Sign, Bolt with Flat Washers, November 10, 1998

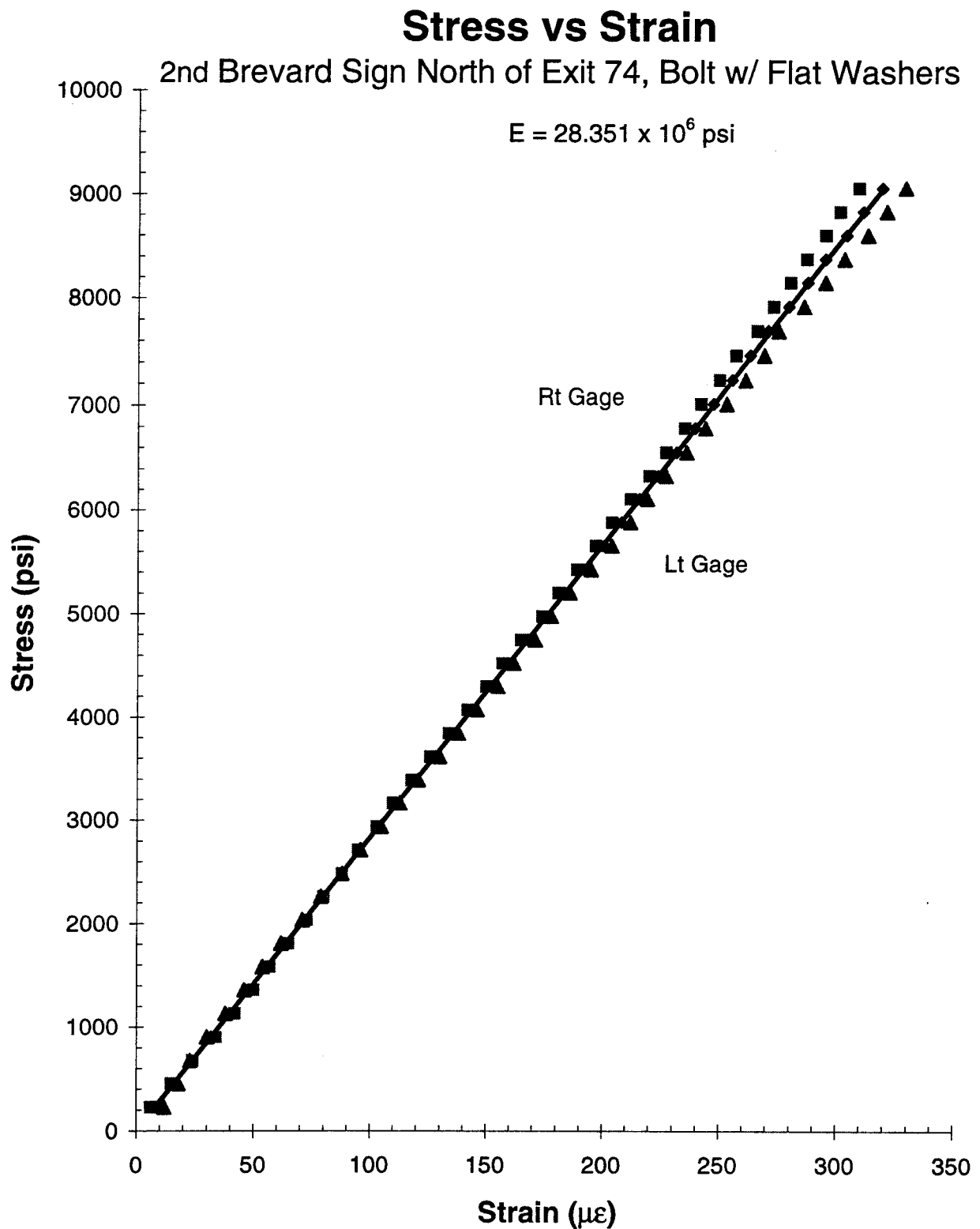


Figure 12 Stress vs Strain, Brevard (2) Sign, Bolt with Flat Washers,
January 22, 1999

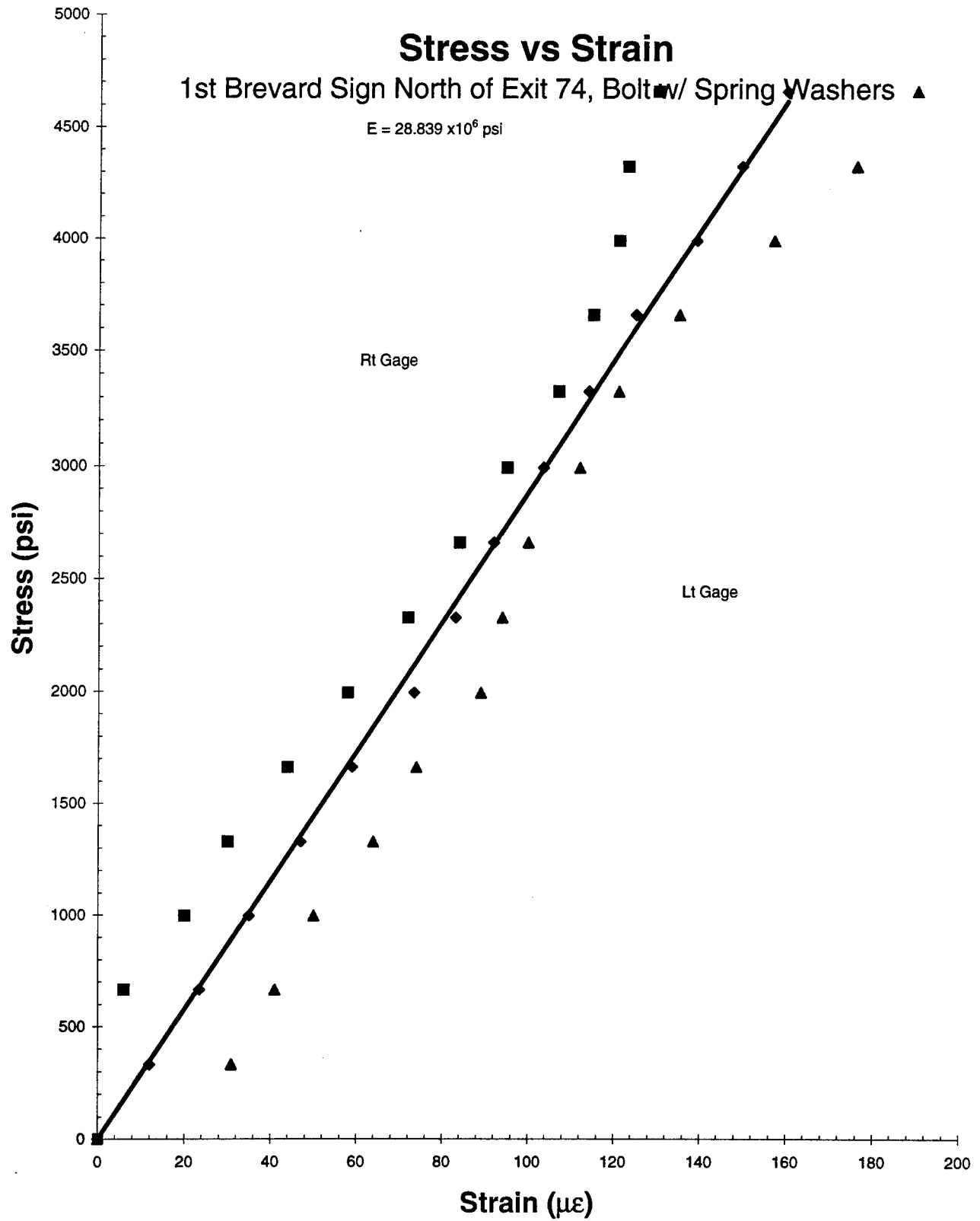


Figure 13 Stress vs Strain, Brevard (1) Sign, Bolt with Spring Washers,
July 14, 1998

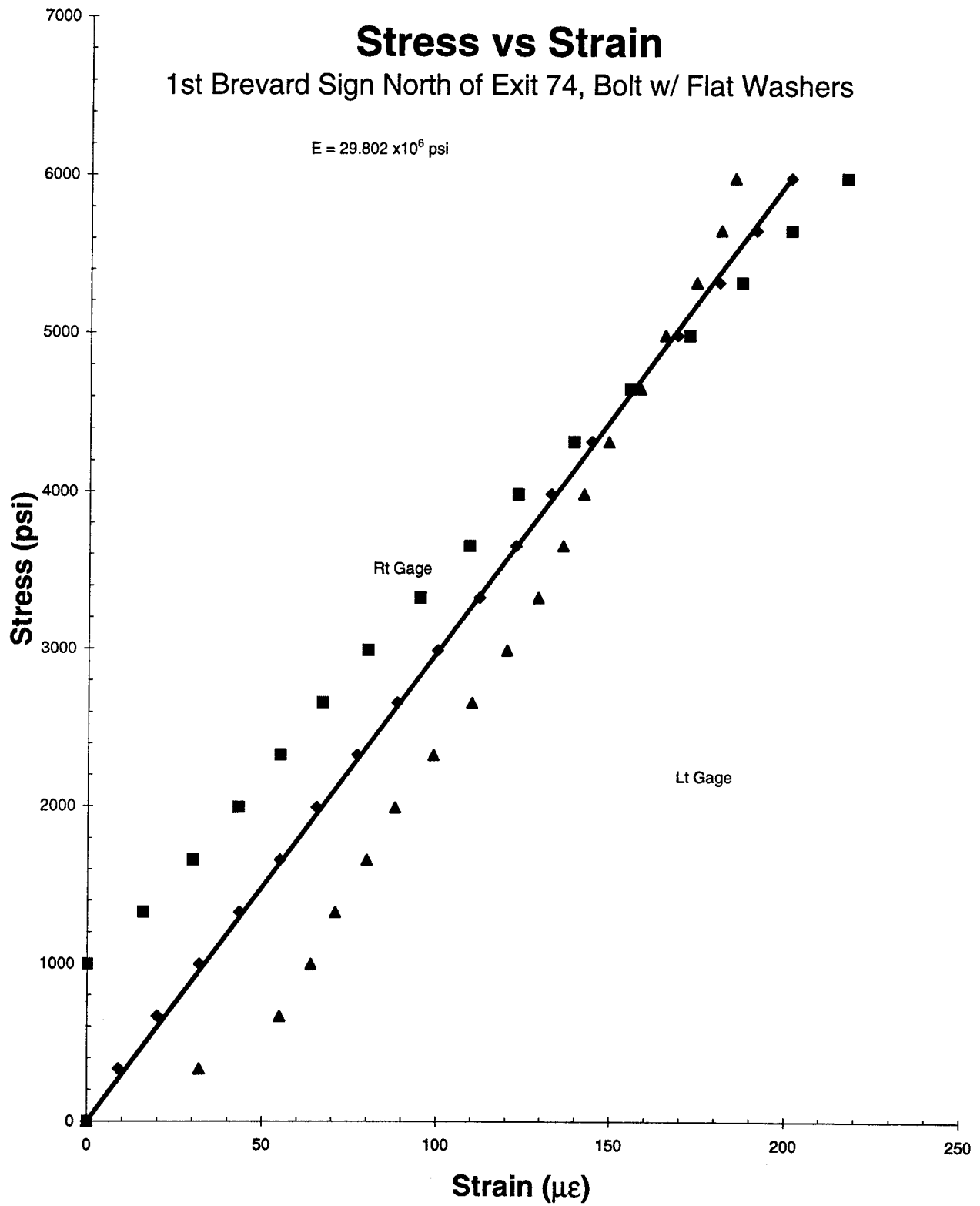


Figure 14 Stress vs Strain, Brevard (1) Sign, Bolt with Flat Washers, July 14, 1998

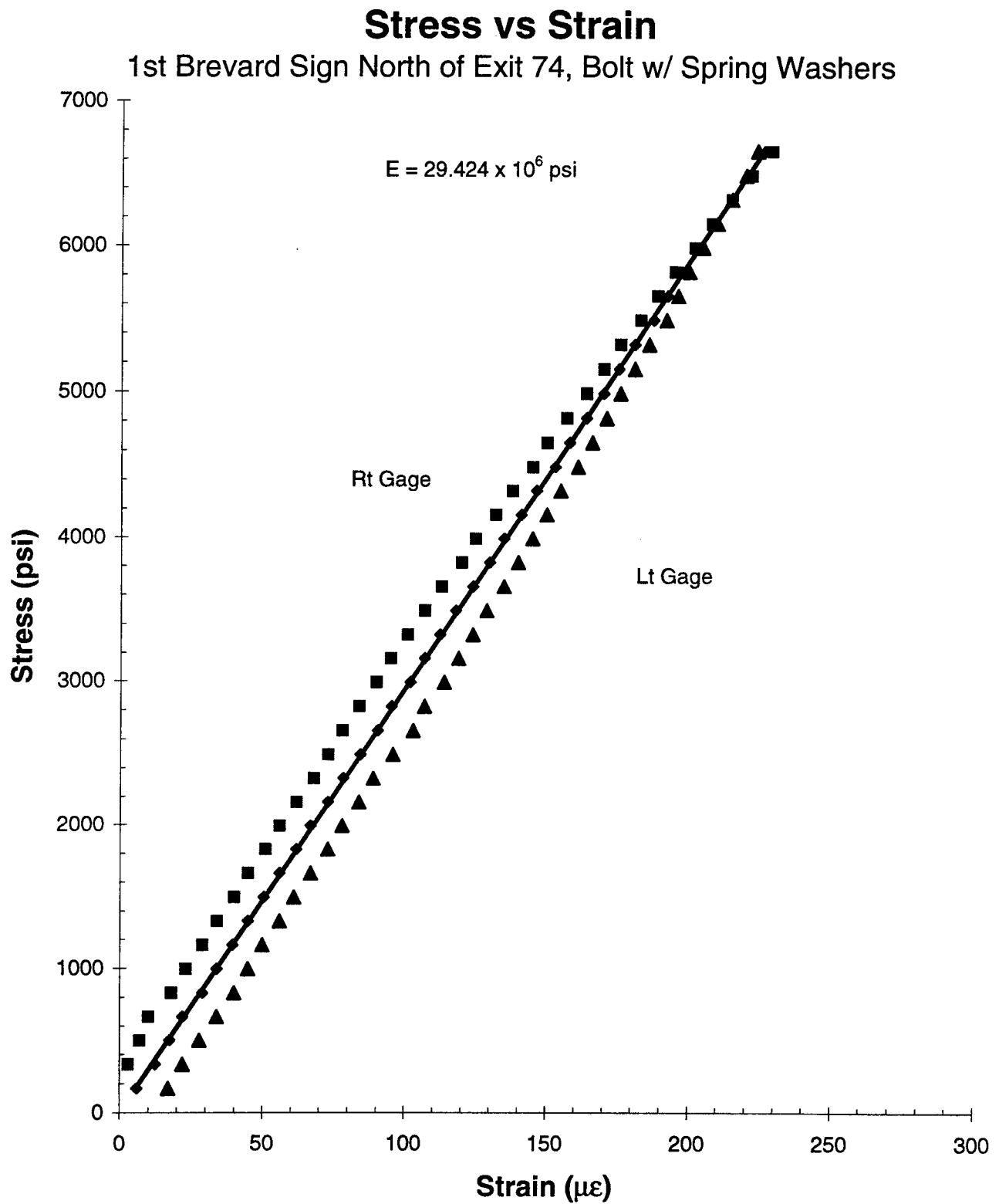


Figure 15 Stress vs Strain, Brevard (1) Sign, Bolt with Spring Washers,
November 19, 1998

Stress vs Strain

Sebastian Sign, Bolt w/ Spring Washers

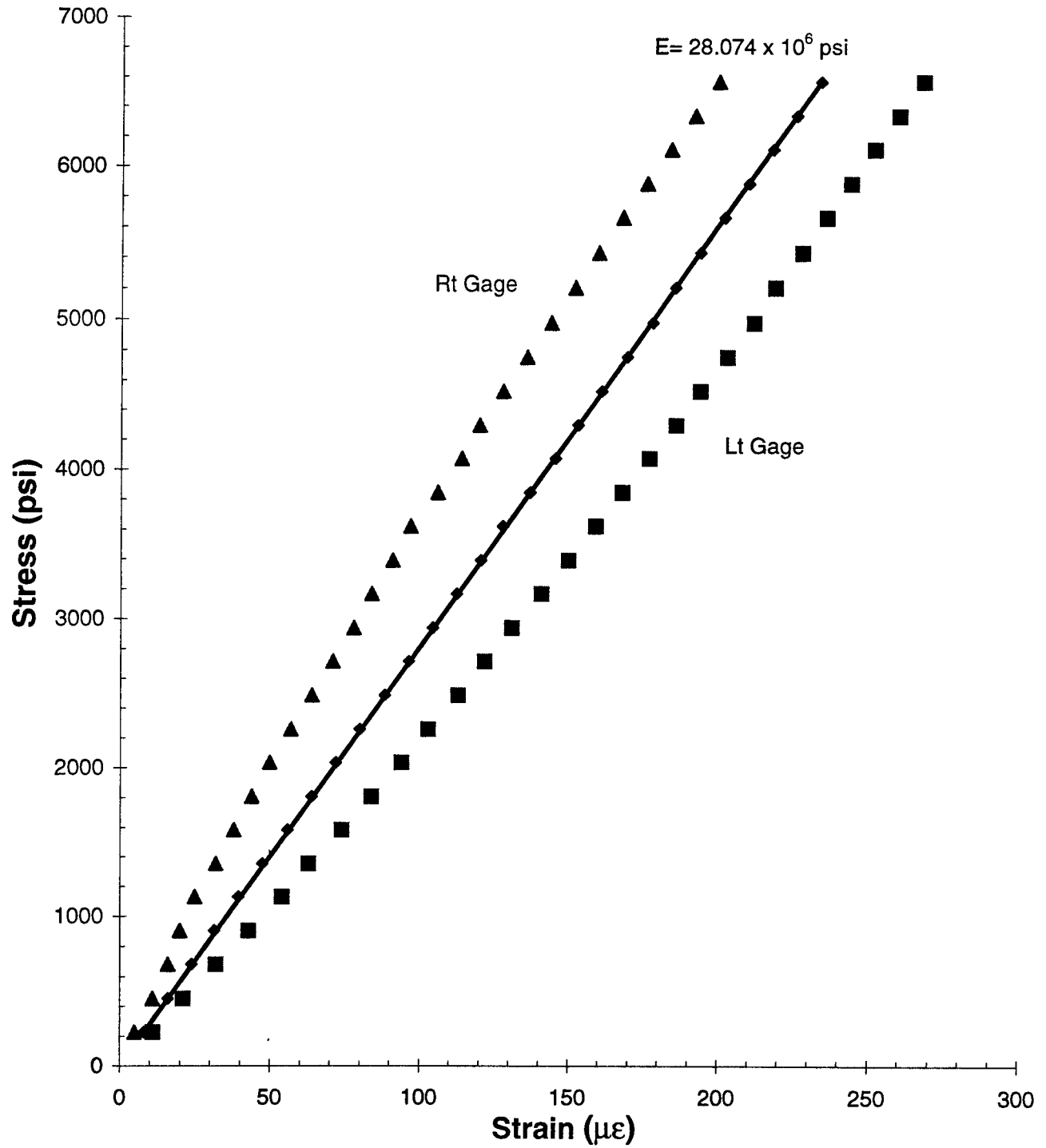


Figure 16 Stress vs Strain, Sebastian Inlet Sign, Bolt with Spring Washers, December 8, 1998

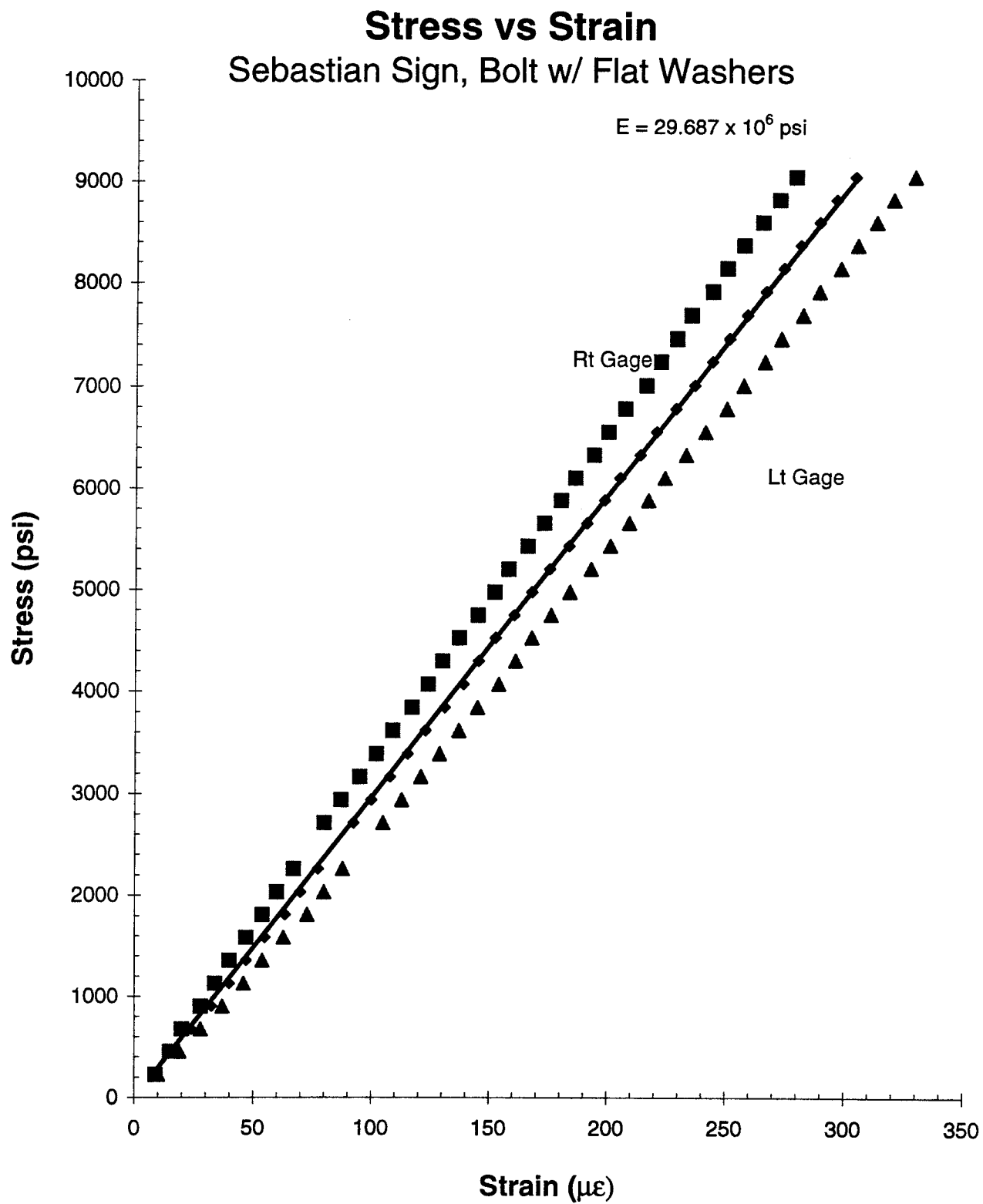


Figure 17 Stress vs Strain, Sebastian Inlet Sign, Bolt with Flat Washers, December 3, 1998

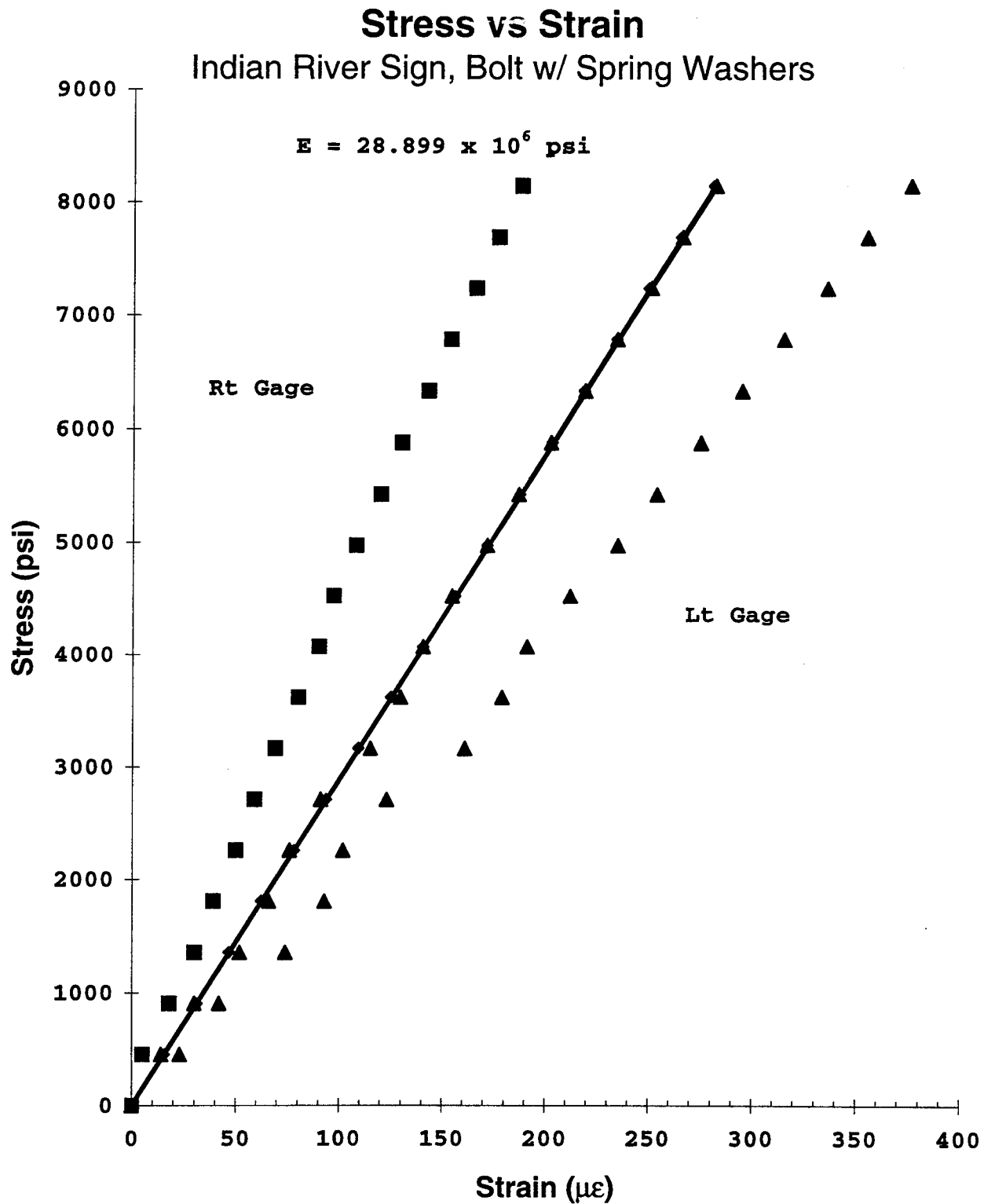


Figure 18 Stress vs Strain, Indian River Sign, Bolt with Spring Washers,
May 15, 1998

Stress vs Strain

Indian River Sign, Bolt w/ Spring Washers

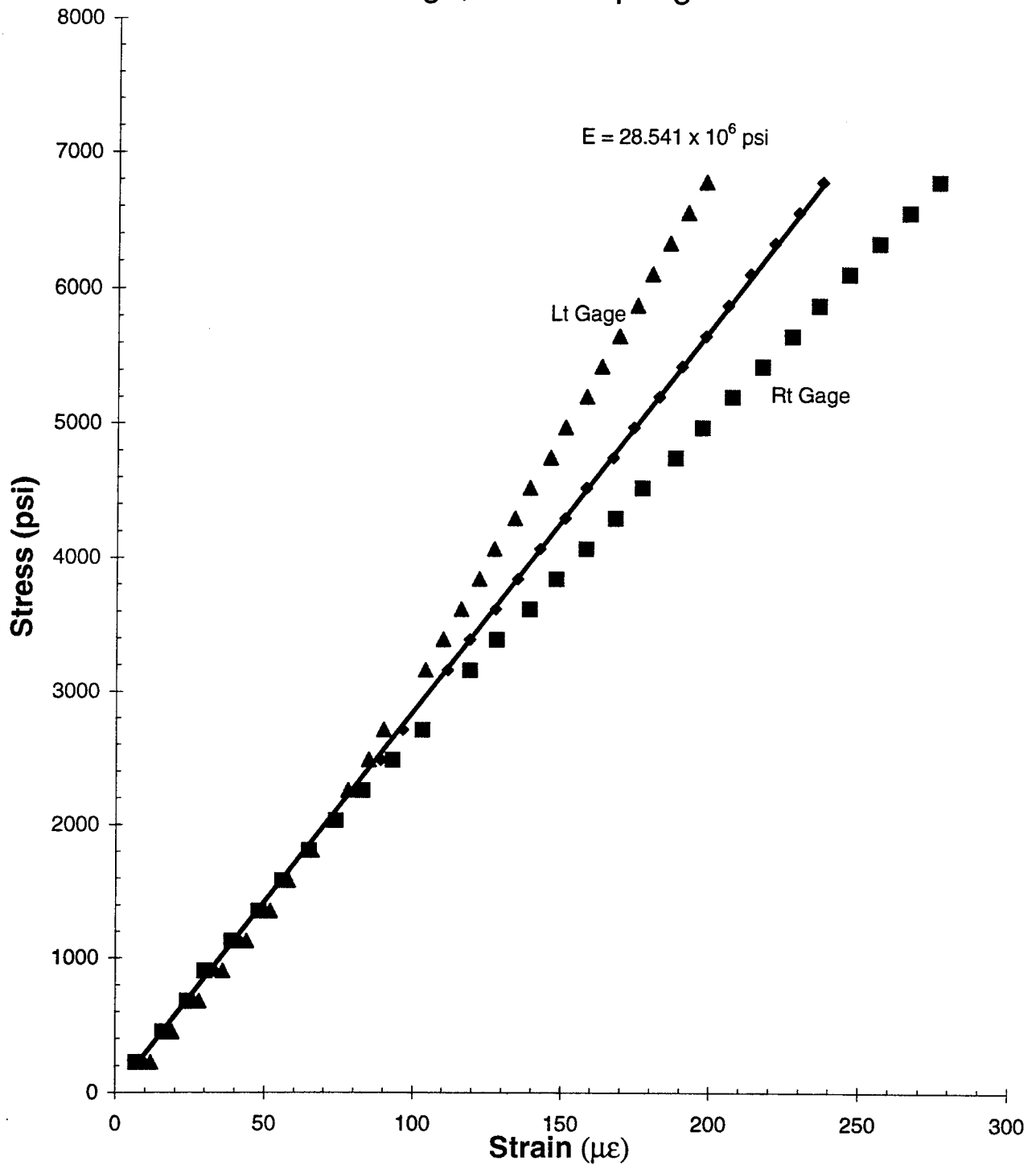


Figure 19 Stress vs Strain, Indian River Sign, Bolt with Spring Washers, February 3, 1999

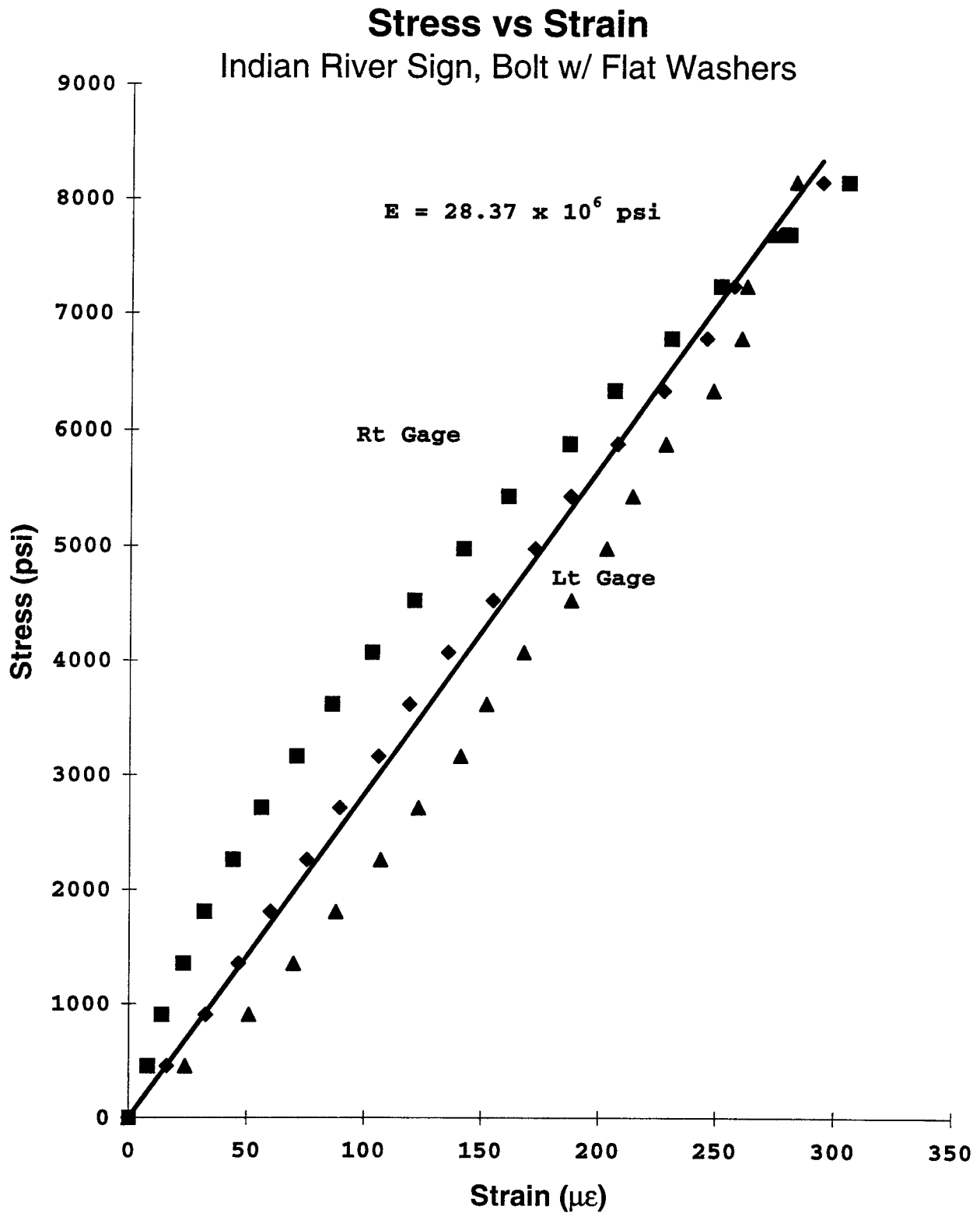


Figure 20 Stress vs Strain, Indian River Sign, Bolt with Flat Washers, May 15, 1998

Stress vs Strain

Indian River Sign, Bolt w/ Flat Washers

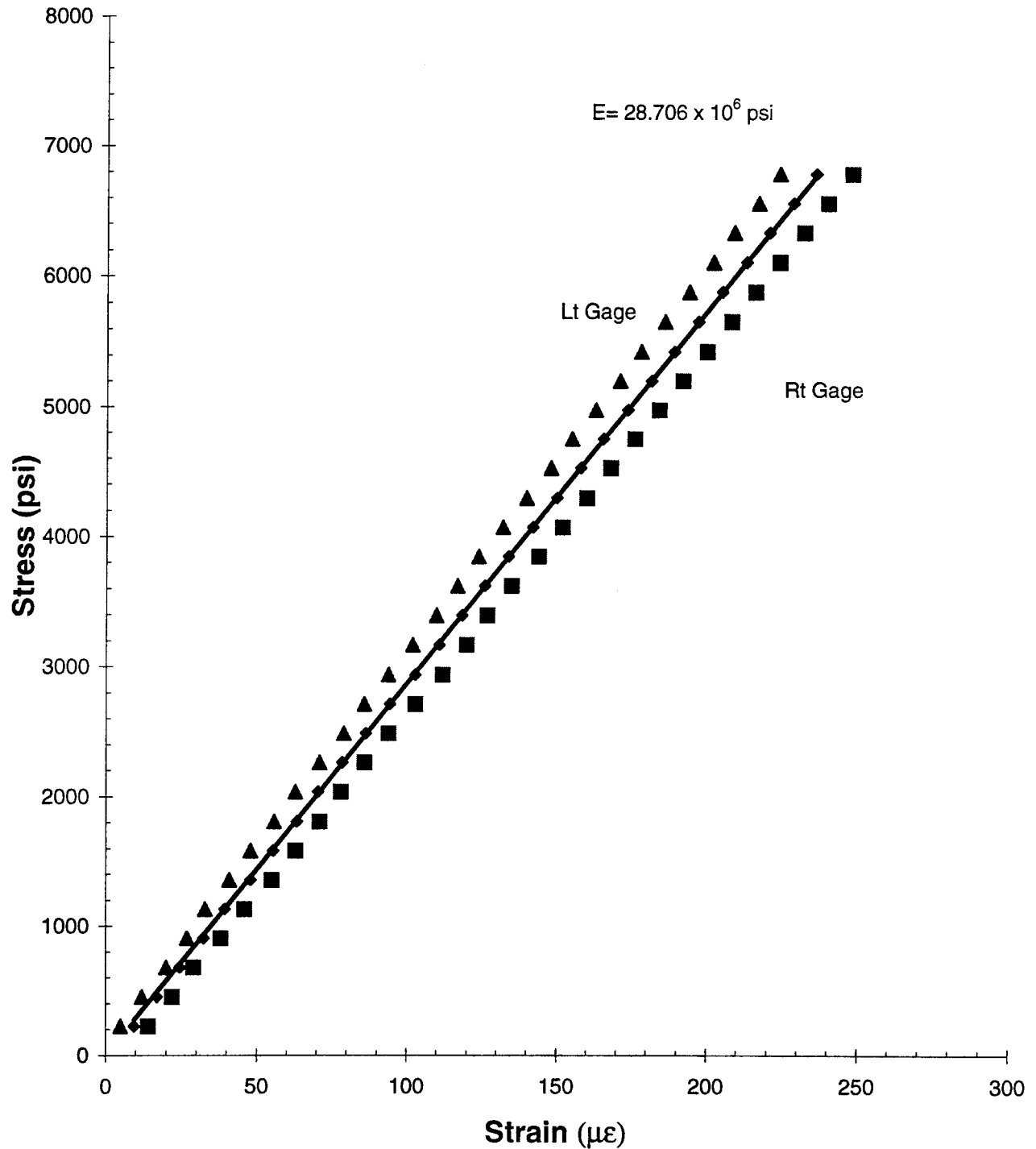


Figure 21 Stress vs Strain, Indian River Sign, Bolt with Flat Washers,
December 8, 1998

Stress vs Strain

Indian River Bolt w/ Flat Washers

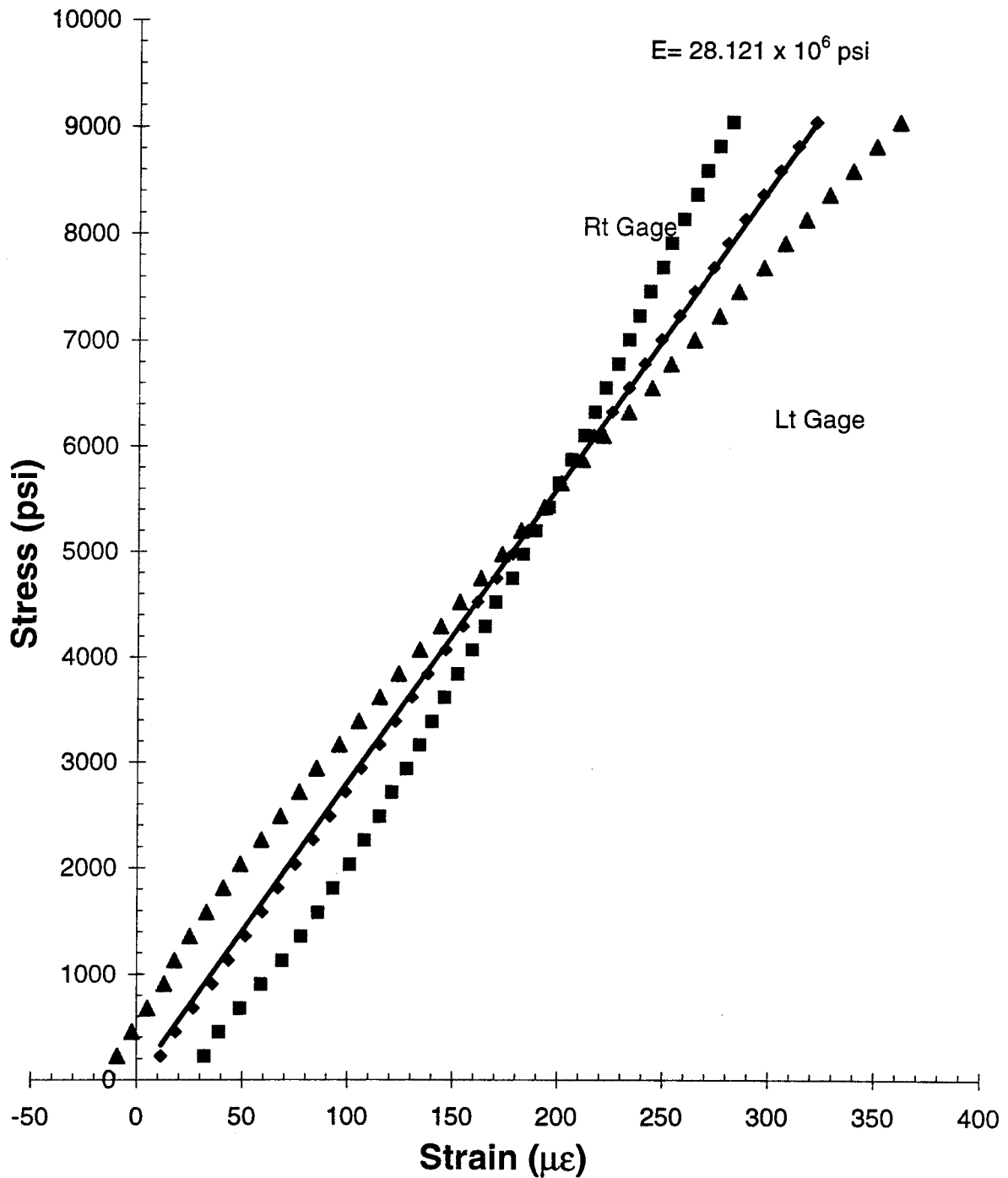


Figure 22 Stress vs Strain, Indian River Sign, Bolt with Flat Washer, February 2, 1999

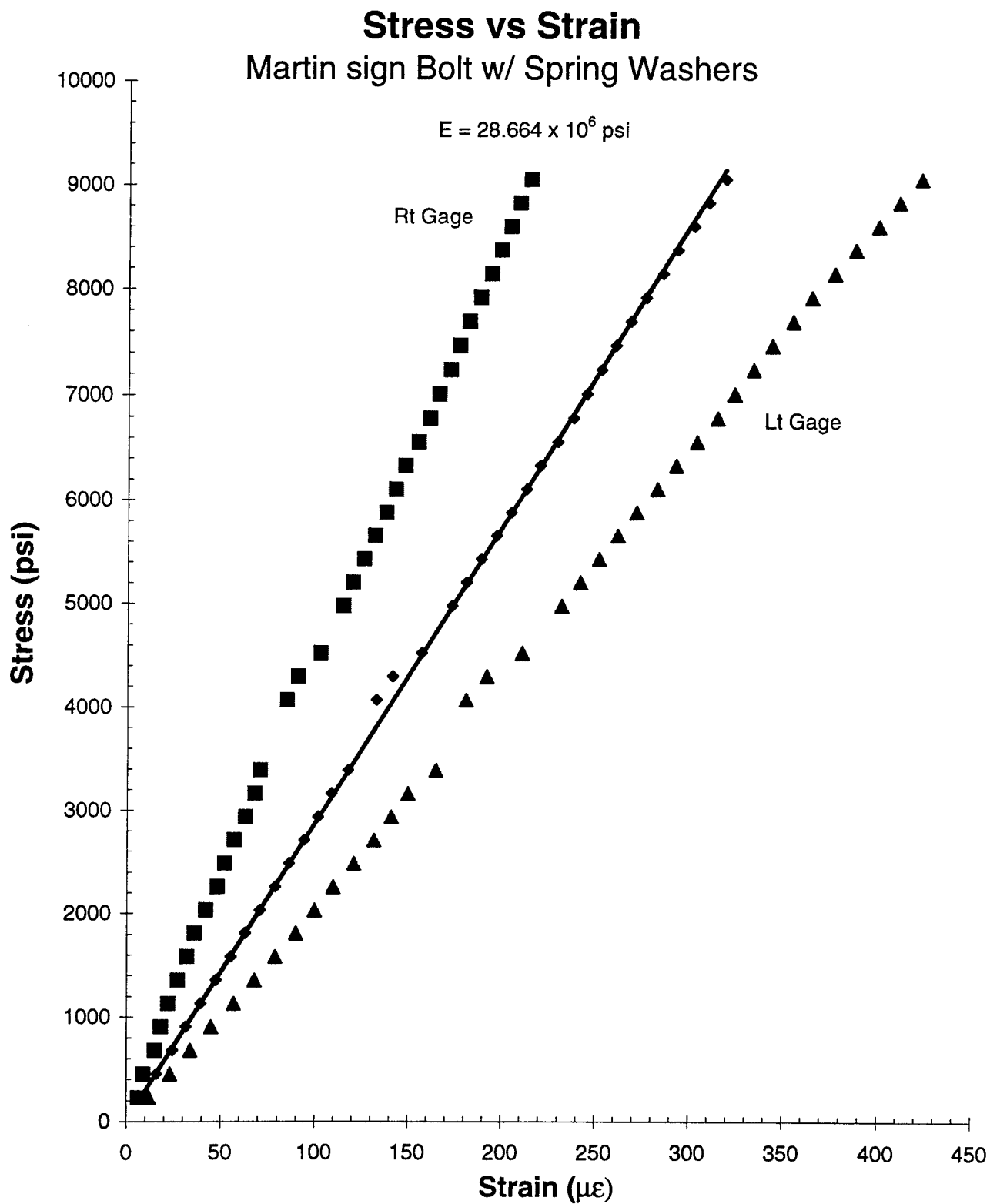


Figure 23 Stress vs Strain, Martin County Sign, Bolt with Spring Washers, December 3, 1998

Stress vs Strain

Martin Sign, Bolt w/ Flat Washers

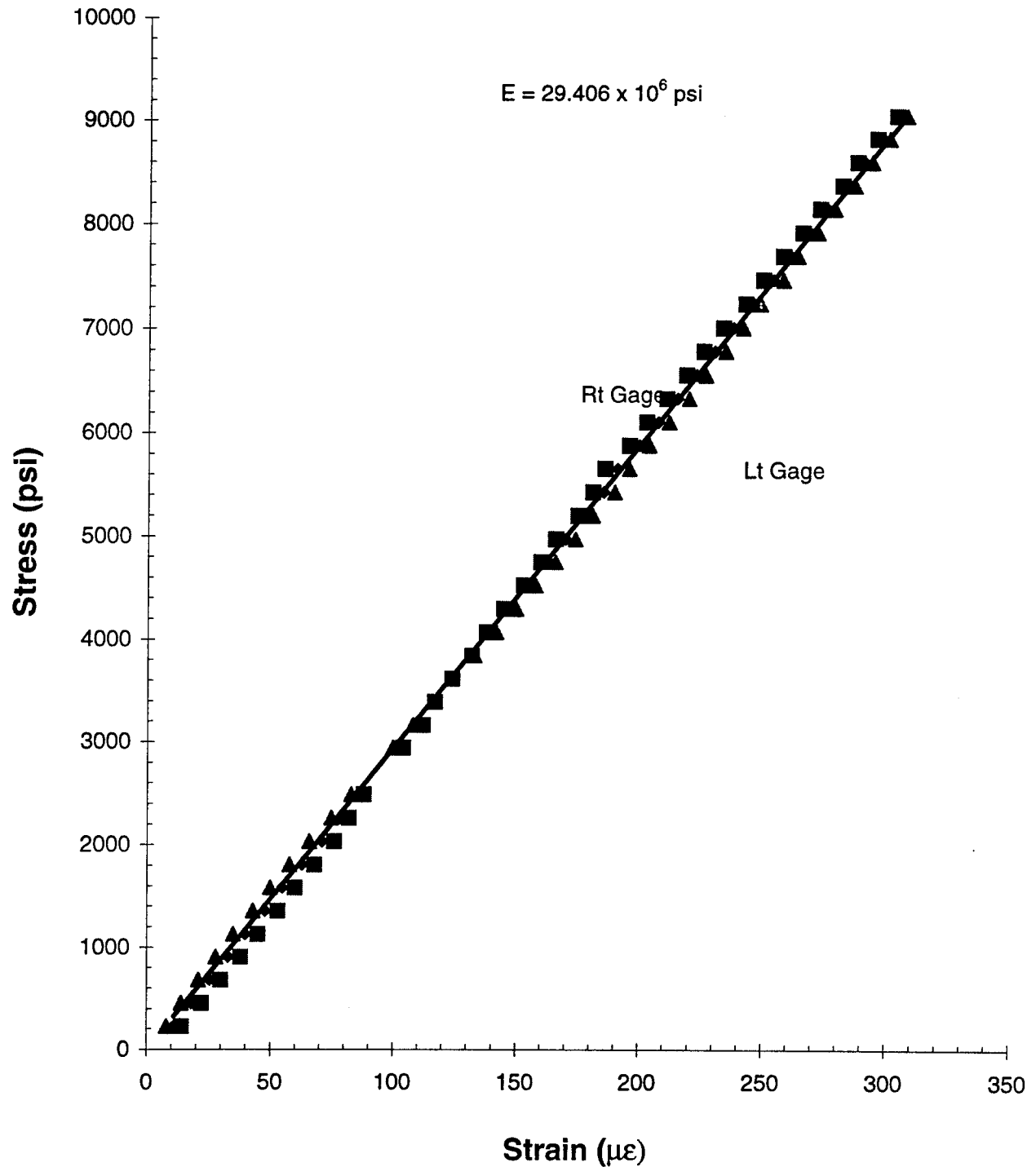


Figure 24 Stress vs Strain, Martin County Sign, Bolt with Flat Washers, December 3, 1998

RESULTS

The results of the field monitoring are presented below for each sign. In each case, the results are tabulated for the bolt with spring washers and the bolt with flat washers. In addition, the variation of tension over time is plotted for each bolt. The plots include also the variation of the temperature over time. Temperature values are represented by white circular dots, while the tension values are represented by black symbols.

Tampa

The Tampa sign bolts were installed on May 18, 1998 and they have been monitored ever since. Different persons have been taking readings ever since they were installed. The sign is located northbound along I-75 just before the I-75/I-4 junction. It is bolted down using 3/4" diameter bolts. Figure 26 shows the location of the sign with respect to I-4.

Tables 4 and 5 list the results of monitoring the bolts from May 18, 1998 to July 16, 1999. Figures 27 and 28 show a plot of tension vs. time for the bolt with spring washers and the bolt with flat washers.

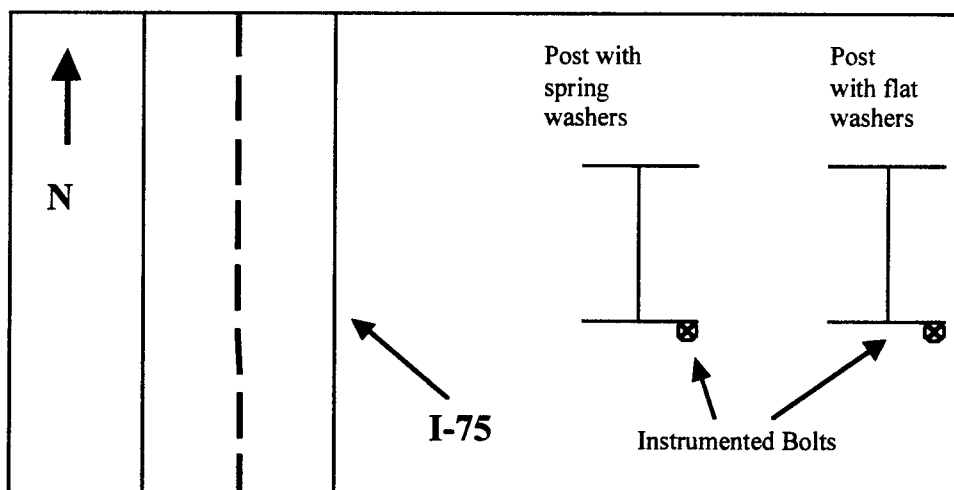


Figure 26 Location of the Tampa Sign with respect to I-75

After the initial installation, the bolt with spring washers show readings were below the lower limit of 2400 lb. The right gage readings also registered negative strains. We suspected a

defective spring washer stack so the bolt was re-torqued on June 10 with a new spring washer stack.

From June 24 to October 16, the readings were within the acceptable range as indicated by the trend line Figure 27.

The left wire was cut from the bolt head on October 23. The bolt was not replaced until February 2, 1999. One of the reasons why the bolt was not replaced for almost two months was that a FDOT crew was needed to assist in lifting the sign off the base. We also decided to focus on the other signs' bolts because most of them were damaged at that time.

The bolt was replaced on February 2, 1999 and the reading that day was in the acceptable range at 2755 lb. The reading increased to 4093 lb. the week after, on February 8. To date, the readings have kept within the acceptable range.

The bolt with flat washers was also installed on May 18, 1998. The tension readings on that day and on May 21 were 2915 lb. and 3613 lb. respectively. The tension readings increased to 4856 lb. and 4375 lb. on May 28 and June 1. The bolt was brought back to the lab to be re-tested and was re-installed on June 10. From June 18, 1998 to July 3, 1999 the tension readings were mostly in the acceptable range. The reading on October 3, 1998 was 865 lb. but this unusual reading was performed by a new research assistant and it could be disregarded. At the end of July, the gage was probably damaged and behaved erratically.

The tension in the short bolt could have been affected when the bolt with the spring washers was re-installed on February 1. A crane lifted the sign up on the post with the flat washers and this could have affected the tension. The bolt was re-torqued on February 8, 1999 and the tension reading that day was still low at 2159 lb. The tension reading decreased to 1787 on February 15 after which it increased to 2703 lb. on February 22.

Location: Tampa; On I-75, south of I-4, sign on right hand when going north.

Sign reads: "Plant City, Lakeland, Exit 53"

Description: Green sign - 12' X 8' X 12' from ground, WBX24 posts

Long Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right	Average	lbs	kN	
					Balance Offset					
ML	5/18/98	0	-	33	320	20	170	2178	9.7	0.083
ML	5/21/98	3	-	32	294	-12	141	1806	8.0	0.102
ML	5/28/98	10	-	28	277	-10	134	1710	7.6	0.101
SON	6/1/98	13	-	28	293	-10	142	1813	8.1	0.100
SON	6/10/98	22	1:30	36	278	15	147	1877	8.3	0.084
SON	6/18/98	30	12:30	36	332	-38	147	1883	8.4	0.118
SON	6/24/98	36	12:00	34	265	169	217	2780	12.4	0.021
SON	7/23/98	65	12:30	35	324	92	208	2665	11.9	0.052
N	8/1/98	83	7:30	26	362	150	256	3260	14.6	0.039
N	8/26/98	98	1:00	34	328	85	207	2646	11.8	0.055
JT	10/3/98	135	2:30	35	319	84	202	2582	11.5	0.055
JT	10/16/98	148	1:00	41	372	84	216	2761	12.3	0.059
JT	10/23/98	155	1:40	32				2921	13.0	0.059
JT	11/4/98	166	1:45							
JT	11/13/98	175	1:25							
JT	11/20/98	182	12:40							
JT	2/1/99	253	11:10	29	90	340	215	2755	12.3	0.055
JT	2/8/99	260	12:35	30	287	352	320	4093	18.2	0.010
JT	2/15/99	267	12:10	31	259	213	236	3024	13.4	0.009
JT	2/22/99	274	11:55	21	245	208	227	2902	12.9	0.008
JT	3/22/99	304	11:45	30	285	189	237	3036	13.5	0.019
JT	3/29/99	311	12:15	35	277	191	234	2988	13.3	0.017
JT	4/5/99	317	11:15	32	279	177	228	2921	13.0	0.021
JT	4/12/99	324	11:55	34	288	172	230	2947	13.1	0.024
JPP	4/19/99	331	12:05	30	271	162	217	2774	12.3	0.024
JPP	5/31/99	373	4:00	34	287	158	223	2851	12.7	0.027
JPP	6/15/99	387	2:00	37	297	166	232	2966	13.2	0.027
JPP	7/3/99	405	12:20	35	285	147	216	2767	12.3	0.030
JPP	7/11/99	413	2:30	38	285	150	218	2787	12.4	0.029
JPP	7/16/99	418	8:35	23	271	99	185	2370	10.5	0.044

bolt retorqued with new spring washer stack

wires were in plastic bag

Wires were dry and in the bag.

Wires were dry and in the bag.

LI wire was cut from the bolt head. Bring crowbar and mallet.

Was not able to replace instrumented bolt.

Was not able to replace instrumented bolt.

Replaced w/ instrumented bolt. New Offsets Lt: 44 Rt: (-24)/876

Retorqued nuts were low. New spring washers. Lt: 43 Rt: (-24)/874

Wires were dry and in the bag.

rusting on galvanized washers, none on stainless washers.

ibdd

ibdd

ibdd

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ibdd

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Table 4 Tension and Eccentricity Values For Tampa Sign, Bolt with Spring Washers

Location: Tampa; On I-75, south of I-4, sign on right hand when going north.

Sign reads: "Plant City, Lakeland, Exit 53"

Description: Green sign - 12' X 6' X 12' from ground, WBX24 posts

Short Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right	Average	lbs	kN	
		5/18/98		Balance Offset	-2/K	864	140			
ML	5/18/98	0	-	33	420	35	228	2915	13.0	0.079
ML	5/21/98	3	-	32	532	32	282	3613	16.1	0.083
ML	5/29/98	10	-	28	728	30	379	4856	21.6	0.086
SON	6/1/98	13	-	28	651	32	342	4375	19.5	0.085
SON	6/10/98	22	1:30	36	390	277	334	4273	19.0	0.016
SON	6/19/98	30	12:30	36	387	231	309	3959	17.6	0.024
SON	6/24/98	36	12:00	34	210	225	218	2787	12.4	0.003
SON	7/23/98	65	12:30	35	344	326	335	4292	19.1	0.003
N	8/11/98	83	7:30	26	305	322	314	4017	17.9	0.003
N	8/25/98	98	1:00	34	52	329	191	2441	10.9	0.068
JT	10/9/98	135	2:20	37	-214	349	68	865	3.8	0.391
JT	10/16/98	141	1:07	36	190	378	284	3639	16.2	0.031
JT	10/23/98	148	12:55	39	162	387	275	3517	15.6	0.038
JT	11/4/98	155	1:30	28	99	322	211	2697	12.0	0.050
JT	11/13/98	166	1:30	23	265	326	296	3786	16.8	0.010
JT	11/20/98	175	1:30	32	106	336	221	2831	12.6	0.049
JT	2/1/99	182	12:40	36	196	352	274	3510	15.6	0.027
JT	2/8/99	253	10:55	26	190	343	267	3414	15.2	0.027
JT	2/15/99	267	1:00	33	217	120	169	2159	9.6	0.027
JT	2/22/99	274	12:00	32	33	246	140	1787	8.0	0.072
JT	3/2/99	274	12:00	21	150	272	211	2703	12.0	0.027
JT	3/22/99	304	11:50	30	141	386	264	3376	15.0	0.044
JT	3/29/99	311	12:20	34	20	361	191	2441	10.9	0.094
JT	4/5/99	317	11:20	32	94	393	244	3120	13.9	0.058
JT	4/12/99	324	12:00	34	89	437	263	3370	15.0	0.062
JT	4/19/99	331	12:10	31	-9	394	193	2466	11.0	0.098
JPP	5/31/99	373	4:00	37	83	517	300	3844	17.1	0.068
JPP	6/15/99	387	2:00	36	-110	590	240	3075	13.7	0.137
JPP	7/3/99	405	12:20	34	76	725	401	5131	22.8	0.076
JPP	7/11/99	413	2:30	38	-192	711	260	3325	14.8	0.163
JPP	7/16/99	418	8:24	23	71	713	392	5022	22.3	0.077

bolt tested in lab and retorqued

*check twice, it is correct

wires were not in plastic bag

Checked the Lt rdg (-2K, 894 offset) 2x. Wires were dry and in bag.

Wires were dry and in the bag. Readings were solid.

Li wire was out of bag. Cut and spliced both wires

Wires were dry and in bag. Bolts were wet.

Wires were dry and in the bag.

Wires were dry and in the bag.

re-torqued using new torque wrench

Wires were dry and in bag.

ibid

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Table 5 Tension and Eccentricity Values For Tampa Sign, Bolt with Flat Washers

Tension vs Time

Tampa Sign, Bolt w/ Spring Washers

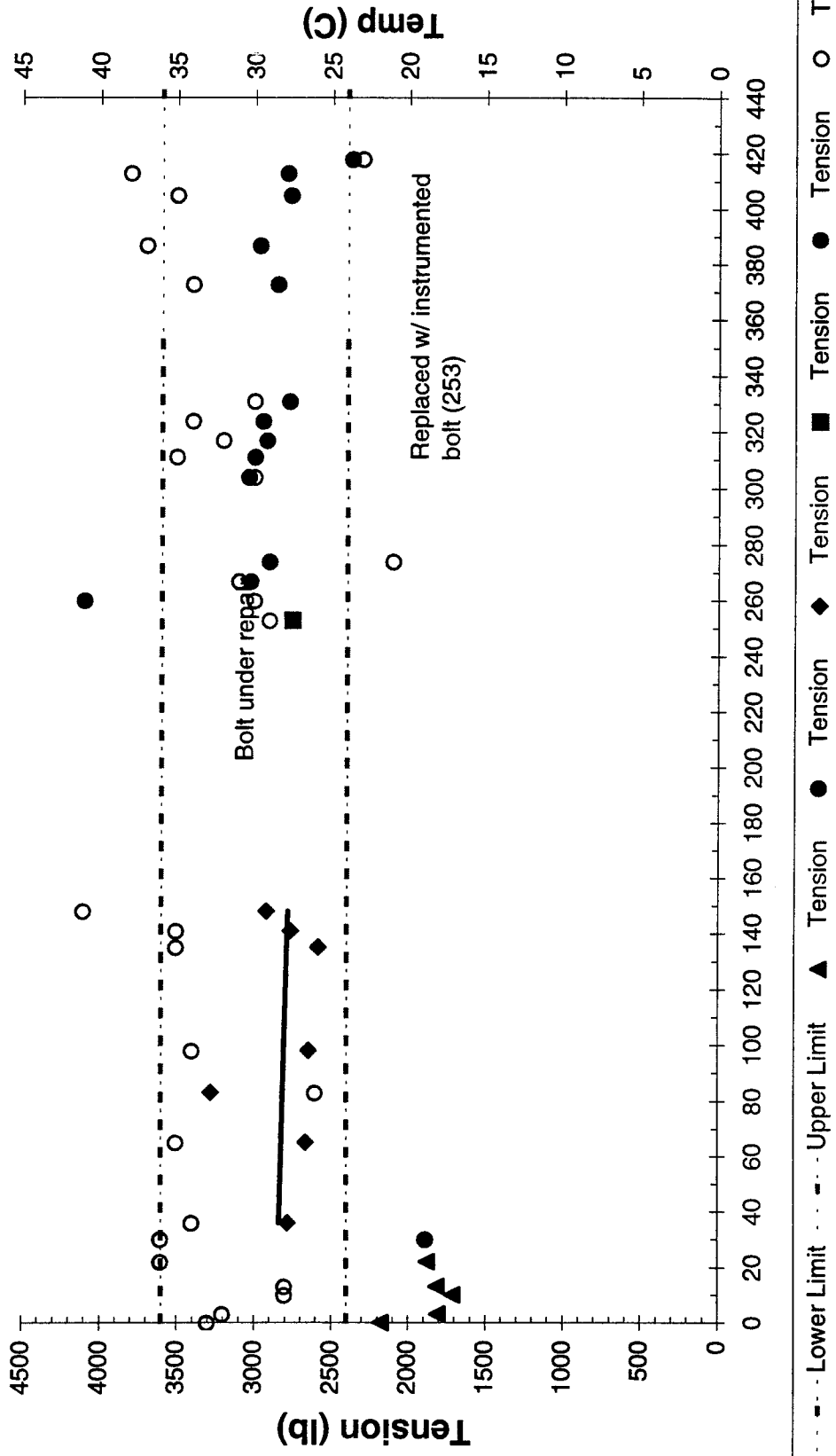
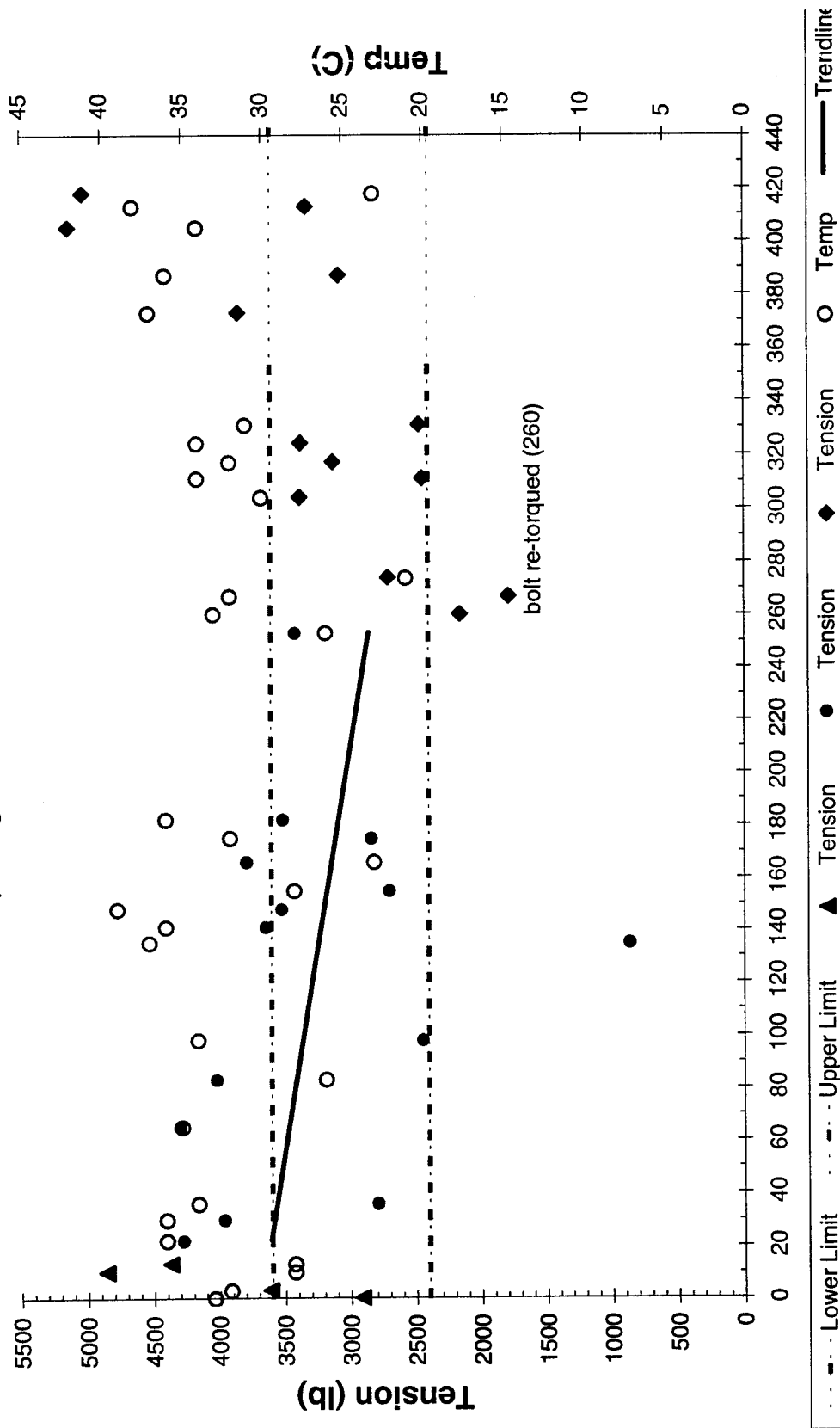


Figure 27 Tension vs Time, Tampa Sign, Bolt with Spring Washers

Tension vs Time

Tampa Sign, Bolt w/ Flat Washers



Days

Figure 28 Tension vs Time, Tampa Sign, Bolt with Flat Washers

Orlando

The Orlando sign bolts were installed on May 16, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located westward along I-4, just before the Highway 528 (Beeline)/I-4 junction. It is bolted down using 3/4" diameter bolts. Figure 29 shows the location of the sign with respect to I-4.

Tables 6 and 7 list the results of monitoring the bolts from May 16, 1998 to April 12, 1999. Figures 30 and 31 show a plot of tension vs. time for the bolt with the spring washers and the bolt with flat washers.

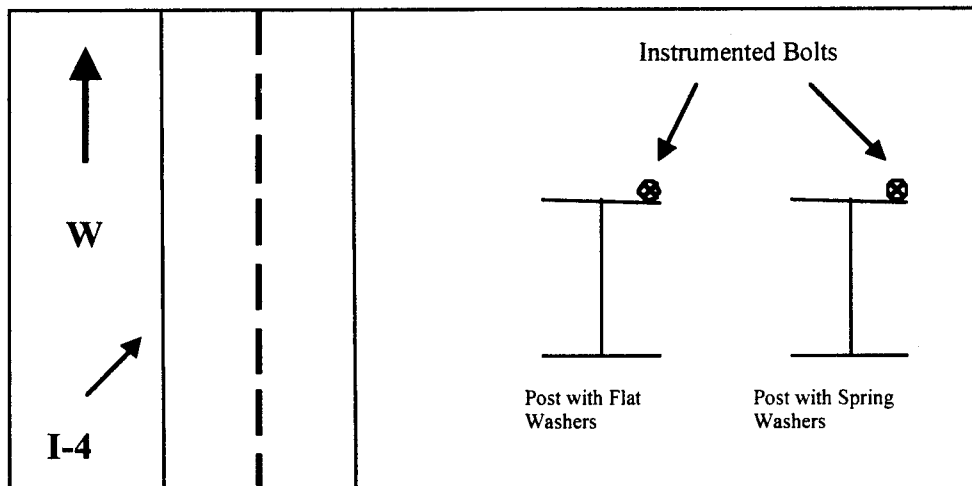


Figure 29 Location of Orlando Sign with respect to I-4

The bolt with strain gages was never replaced and the bolt was re-torqued. The spring washers were able to keep the tension within the acceptable range from May 16, 1998 to February 22, 1999. After that date, the readings were below the allowable range. On April 12, the bolt was removed. A tensile test in the lab yielded a value of 27,117 ksi for the modulus of elasticity, slightly below the expected value of 29,000 ksi, which might indicate a deterioration of the strain gage.

The initial reading for the bolt with flat washers was 2601 lb. The readings increased dramatically to 23420 lb. on May 28 and 45008 lb. on June 1. The bolt was brought back and re-instrumented. The bolt was re-installed on June 10 and a reading of 2671 lb. was recorded.

After that date, the readings were below 2400 lb. until September 26. The strain gage wires were ripped off on October 3 and the newly re-instrumented bolt was re-installed on November 4. The bolt was re-torqued on November 13 and the readings decreased to 922 lb. on November 20.

The bolt was re-installed on December 2, 1998 with new offsets and a measured modulus of elasticity of 27,761 ksi. The readings have been below the 2400 lb. until January 25, 1999.

The bolt was re-installed and re-aligned on February 1, 1999. One can notice that one of the strain readings was always negative for most of the readings. This meant that the bolt was not aligned properly and as a result, the bolt was subjected to bending. This is the reason for the re-torquing of the bolt on February 8, 15, and 22. The bolt was finally removed and brought back to the lab. A tensile test revealed a modulus of elasticity of 36,047 ksi, a 33% increase over the value measured in January. This indicate a defect in the strain gage, probably in the bond between gage and bolt. This defect explains partially the erratic behavior of the bolt during the last weeks of testing.

Description: Green Siam - 20' X 12' X 11' from around. W8X24 posts

Table 6 Tension and Eccentricity Values For Orlando Sign, Bolt with Spring Washers

Location: Orlando, Last sign before exit 28 going west.
 Sign reads: "Exit 28, I-4, Toll 528, Cape Canaveral, Titusville."
 Description: Green Sign - 20' X 12' X 11' from ground, W8X24 posts

Short Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right	Average	lbs	kN	
					418	(-24)/774				
ML	5/16/98	0	-	24	40	366	203	2601	11.6	0.075
ML	5/21/98	5	-	29	1116	399	758	9705	43.2	0.044
ML	5/28/98	12	-	29	3313	343	1828	23420	104.2	0.076
SON	6/1/98	15	-	29	6670	356	3513	45008	200.2	0.084
SON	6/10/98	24	12:00	36	736	-319	209	2671	11.9	0.237
SON	6/18/98	32	11:20	35	631	-320	156	1992	8.9	0.287
SON	6/24/98	38	10:35	35	619	-314	153	1954	8.7	0.287
SON	7/8/98	52	10:50	33	575	-306	135	1723	7.7	0.307
SON	7/15/98	59	10:30	28	545	-310	118	1505	6.7	0.341
SON	7/23/98	67	11:10	35	531	-315	108	1384	6.2	0.367
N	8/12/98	86	8:00	29	542	-295	124	1582	7.0	0.318
N	8/26/98	100	11:30	33	275	0	138	1762	7.8	0.094
JT	10/3/98	137	12:41	38						
JT	10/9/98	143	11:50	35						
JT	10/16/98	150	11:35							
JT	10/23/98	157	12:10		189	145	167	2140	9.5	0.012
JT	11/4/98	168	12:05	25	-210	430	110	1409	6.3	0.273
JT	11/13/98	177	12:05	29	-55	249	97	1243	5.5	0.147
JT	11/20/98	184	11:10	30	128	16	72	922	4.1	0.073
JT	12/2/98	196	10:15	25	592	-200	196	2404	10.7	0.189
			1:10	28	524	-200	162	1987	8.8	0.209
			2:10	27	517	-200	159	1944	8.6	0.212
JT	12/11/98	205	10:10	21	480	-230	125	1533	6.8	0.266
			12:40	29	450	-170	140	1717	7.6	0.208
			1:40	26	448	-170	139	1705	7.6	0.208
JT	1/25/99	249	11:25	26	368	-197	84.5	1036	4.6	0.312
JT	2/1/99	255	1:10	21	500	-140	180	2208	9.8	0.167
JT	2/8/99	262	10:55	25	-222	500	139	1705	7.6	0.243
JT	2/15/99	269	10:35	21	344	-165	89.5	1098	4.9	0.267
JT	2/22/99	276	10:25	12	678	-242	216	2674	11.9	0.198
JT	3/22/99	306	10:25	23	243	-271	-14	-172	-0.8	-1.721
JT	3/29/99	313	10:35	31	147	-346	-99.5	-1220	-5.4	-0.232
JT	4/5/99	319	10:00	28	280	-130	75	920	4.1	0.256
JT	4/12/99	326	10:20	29	360	-100	130	1594	7.1	0.166

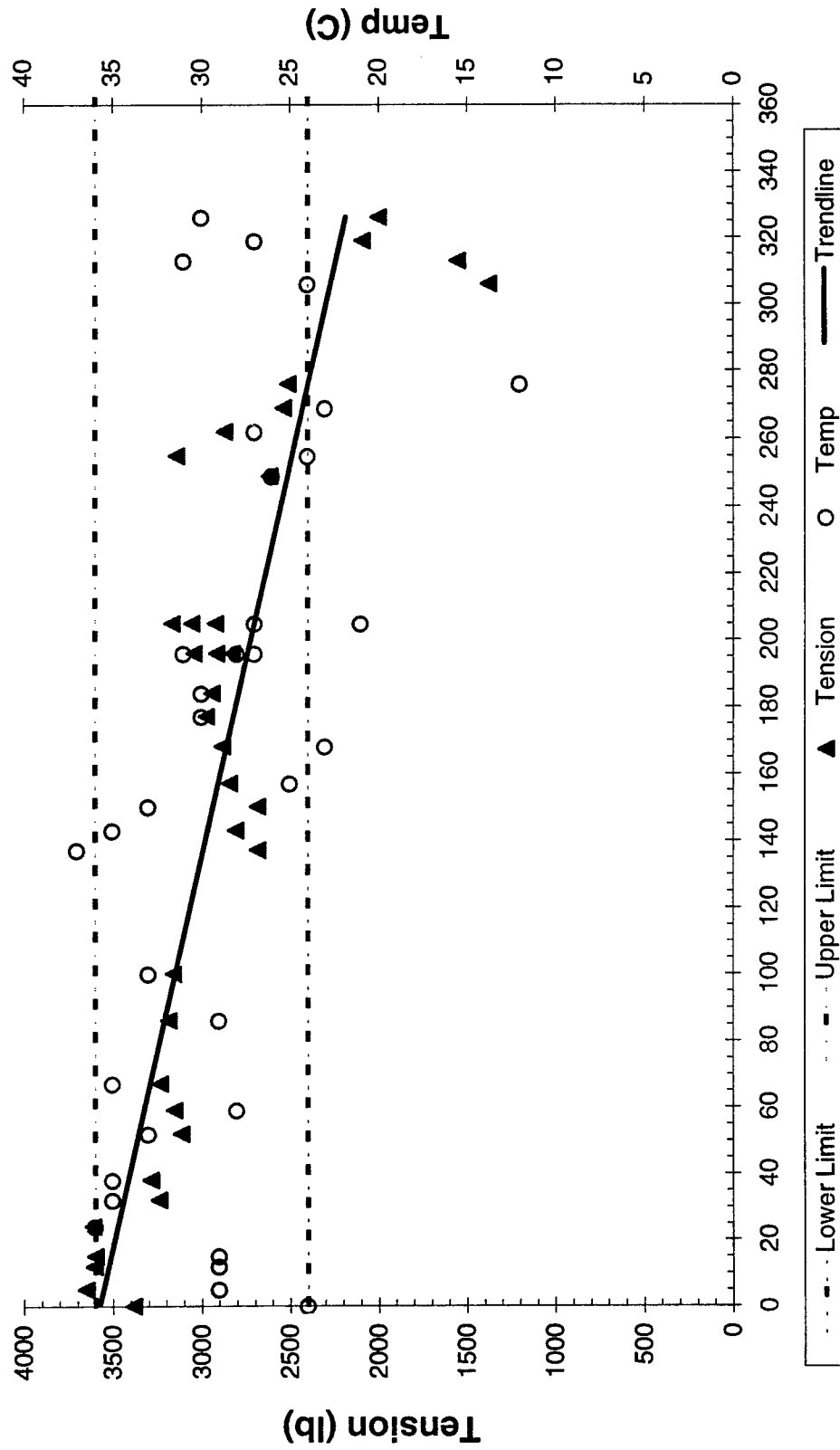
bolt tested in lab and retorqued

*check twice, it is correct
 Strain gage wires were ripped off from the bolts.
 Replaced instrumented bolt with regular bolt.
 Have not replaced regular bolt with an instrumented bolt
 Replaced regular bolt with newly repaired instrumented bolt. Did not read Temp.
 Re-torqued bolt. New Offsets: Lt:135 Rt: (-24)/718. Wires were dry and in bag.
 Wires were dry and in the bag.
 Average was very low. Replaced with a regular bolt.
 Replaced w/ instrumented bolt. New Offsets: Lt: 114 Rt: (-24)/722. New E = 27.761x106ksi

Wires were dry and in the bag.
 ibd
 ibd
 Re-installed & re-aligned the bolt. New Offsets Lt: 120 Rt (-24)694
 Retorqued w new wrench. New Offsets Lt: 250 Rt (-24)678
 Retorqued, initial tension rdgs were negative. Lt:345 Rt:(-24)781
 Retorqued. Lt:418 Rt:(-24)774
 Wires were dry and in the bag.
 ibd
 readings fluctuated; replaced w/ regular bolt permanently

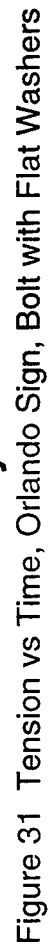
Table 7 Tension and Eccentricity Values For Orlando Sign, Bolt with Flat Washers

Tension vs Time Orlando Sign, Bolt w/ Spring Washers



Days
Figure 30 Tension vs Time, Orlando Sign, Bolt with Spring Washers

Orlando Sign, Bolt w/ Flat Washers



Brevard (2)

The Brevard (2) sign bolts were installed on May 16, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along I-95, past Exit 74. It is bolted down using 3/4" diameter bolts. Figure 32 shows the location of the sign with respect to I-95.

Tables 8 and 9 list the results of monitoring the bolts from May 16, 1998 to April 19, 1999. Figures 33 and 34 show a plot of tension vs. time for the bolt with the spring washers and the bolt with flat washers.

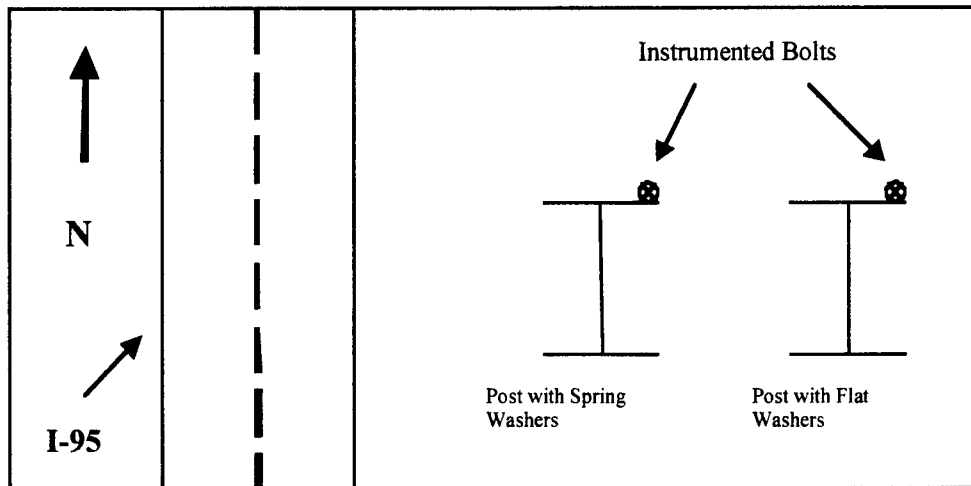


Figure 32 Location of Brevard (2) Sign with respect to I-95

The spring washers were able to hold the tension within the acceptable range from May 16, 1998 through November 20, 1998 except for two days: October 23 at 1883 lb. and November 4 at 1838 lb. These readings might have been affected by the drop in temperature in those days.

Consequently, multiple readings were done for two days to test whether the temperature had any effects on the strain gages. The readings taken on those two days, December 2 and 11, seemed to indicate that the tension varied with the temperature. However, temperature tests performed in the lab indicated that the temperature should have no effect on the strain gages. Thus, it was concluded that the gages or the adhesive might have some defects. The bolt was removed and brought back to be re-instrumented on January 25, 1999.

The newly re-instrumented bolt was re-installed on February 2, 1999 with new offsets and with a measured modulus of elasticity of 28,634 ksi. The readings have kept within the acceptable range, until April 19, 1999, when the readings were discontinued.

The bolt with the flat washers was installed on May 16, 1998. The reading on that day was 3523 lb., within the acceptable range. The readings increased to a peak of 6739 lb. on May 28. The bolt was taken back to the lab and it was re-installed on June 1 where the reading was 6009 lb.

On June 10, the bolt was re-installed after the bolt was brought back to the lab to have the lead wires resoldered. Readings were taken from June 24 to September 26 which saw the readings fluctuate from a low of 1557 lb. to a high of 6239 lb. The bolt was submerged in water for at least a day, on September 10.

From October 3 to October 23, 1998, the right gage registered and infinite resistance on the Strain Gage Tester which meant that it was disconnected. The bolt was removed on November 3 and was re-installed on November 13 with a measured modulus of elasticity of 28,112 ksi. After that date, the readings increased dramatically to 11060 lb. and 26565 lb. on December 2, 1998. The bolt was replaced and re-installed on January 25, 1999 with a modulus of elasticity of 28,112 ksi. The reading on that day was low at 1165 lb. The following reading on February 1 was even lower at 777 lb. The bolt was re-torqued using a new torque wrench on February 8. The readings have been decreasing until April 19, 1999, when the readings were discontinued. A tensile test in the lab showed a value of 28,115 ksi for the modulus of elasticity, with no change from the value measured before installation in the field. The gage was then judged to be sound.

Location: Brevard; second sign past exit 74 going north.

Sign reads: "Cocoa, Orlando, Next 2 exit."

Description: Green Sign - 12' X 8' X 15' from ground, W8X24 posts

Long Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Balance Offset >> (-2K) 716	Left (-2K) 716	Right (-2K) 839	lbs	kN	
							Average			
ML	5/16/98	0	-	27	298	137	218	2787	12.4	0.035
ML	5/21/98	5	-	29	266	249	258	3298	14.7	0.003
ML	5/28/98	12	-	27	246	262	254	3254	14.5	0.003
SON	6/1/98	15	-	29	257	241	249	3190	14.2	0.003
SON	6/10/98	24	10:45	33	207	227	217	2780	12.4	0.004
SON	6/18/98	32	10:15	34	218	237	228	2915	13.0	0.004
SON	6/24/98	38	9:30	33	170	277	224	2863	12.7	0.022
SON	7/8/98	52	9:45	32	180	310	245	3139	14.0	0.025
SON	7/16/98	60	8:40	28	158	330	244	3126	13.9	0.033
SON	7/23/98	67	10:00	33	170	333	252	3222	14.3	0.030
N	8/11/98	85	1:10	34	244	114	179	2293	10.2	0.034
N	8/26/98	100	10:30	32	165	343	254	3254	14.5	0.033
ML	9/10/98	114	10:18							
ML	9/10/98	114	5:01							
ML	9/19/98	123	10:05	40	147	347	247	3165	14.1	0.038
ML	9/19/98	123	6:45	31	135	379	257	3293	14.6	0.045
ML	9/26/98	130	10:25	33	120	368	244	3126	13.9	0.048
ML	9/26/98	130	2:50	42	142	304	223	2857	12.7	0.034
JT	10/3/98	137	11:10	31	130	387	259	3312	14.7	0.047
JT	10/9/98	143	10:23	30	117	369	243	3113	13.8	0.049
JT	10/16/98	150	10:20	30	118	347	233	2979	13.3	0.046
JT	10/23/98	157	10:25	23	89	205	147	1883	8.4	0.037
JT	11/4/98	168	10:40	25	89	198	144	1838	8.2	0.036
JT	11/13/98	177	10:45	27	132	392	262	3357	14.9	0.047
JT	11/20/98	184	9:00	27	115	418	267	3414	15.2	0.053
JT	12/2/98	196	9:00	33	141	404	273	3491	15.5	0.045
		196	12:00	34	91	322	207	2646	11.8	0.052
		196	3:30	26	83	225	154	1973	8.8	0.043
		196	4:30	25	84	213	149	1903	8.5	0.041
JT	12/11/98	205	8:55	23	96	386	241	3098	13.7	0.056
		206	11:40	27	102	301	202	2582	11.5	0.046
		206	3:25	28	102	248	175	2242	10.0	0.039
JT	1/25/99	249	10:00							
JT	2/1/99	255	3:10							
JT	2/12/99	266	10:30	27	324	203	264	3333	14.8	0.022
JT	2/15/99	269	9:15	17	295	173	234	2960	13.2	0.024
JT	2/22/99	276	9:00	9	270	147	209	2638	11.7	0.028
JT	3/22/99	306	9:05	22	297	180	239	3017	13.4	0.023
JT	3/29/99	313	9:15	28	306	196	251	3175	14.1	0.021
JT	4/5/99	319	8:50	25	293	185	239	3023	13.4	0.021
JT	4/12/99	326	9:10	26	304	184	244	3087	13.7	0.023
JT	4/19/99	333	9:35	25	293	181	237	2998	13.3	0.022

wires ripped off duct tape sign
Bolts still under water

wires were in bag

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag. Rusting on all three washers. Readings done 2x.

Wires were dry and in the bag. Bolts were wet.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Wires were dry and in the bag.

Table 8 Tension and Eccentricity Values For Brevard (2) Sign, Bolt with Spring Washers

Location: Brevard; second sign past exit 74 going north.

Sign reads: "Cocoa, Orlando, Next 2 exit."

Description: Green Sign - 12' X 8' X 15' from ground, W8X24 posts

Short Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right (-2k/844)	Average	lbs	kN	
	5/16/98	0	-	27	228	393	275	3523	15.7	0.040
ML	5/21/98	5	-	29	415	477	446	5714	25.4	0.007
ML	5/28/98	12	-	27	532	520	526	6739	30.0	0.001
SON	6/7/98	15	-	29	452	486	469	6009	26.7	0.003
SON	6/10/98	24	10:45	33	-60	712	326	4177	18.6	0.111
SON	6/24/98	38	9:30	33	-87	330	122	1557	6.9	0.161
SON	7/8/98	52	9:45	32	295	475	385	4933	21.9	0.022
SON	7/16/98	60	8:40	28	367	607	487	6239	27.8	0.023
SON	7/23/98	67	10:00	33	335	570	453	5797	25.8	0.024
N	8/11/98	85	1:10	34	208	541	375	4798	21.3	0.042
N	8/26/98	100	10:30	32	270	550	410	5253	23.4	0.032
ML	9/10/98	114	10:18							
ML	9/10/98	114	5:01							
ML	9/19/98	123	10:05	40	301	268	285	3645	16.2	0.005
ML	9/19/98	123	6:45	31	389	335	362	4638	20.6	0.007
ML	9/26/98	130	10:25	33	443	297	370	4740	21.1	0.018
ML	9/26/98	130	2:50	42	320	232	276	3536	15.7	0.015
JT	10/3/98	137	11:20	32	500					
JT	10/9/98	143	10:32	31	509					
JT	10/16/98	150	10:30	28	361					
JT	10/23/98	157	10:35	23	150					
JT	11/4/98	168	10:50							
JT	11/13/98	177	4:10	26	171	363	267	3316	14.8	0.034
JT	11/20/98	184	9:40	25	232	620	426	5291	23.5	0.043
JT	12/2/98	196	11:55	31	224	1557	891	11060	49.2	0.070
JT	12/2/98	196	3:25	25	246	4032	2139	26585	118.2	0.083
JT	12/11/98	205								
JT	1/25/99	249	9:50	24	108	78	93	1165	5.2	0.015
JT	2/1/99	255	3:15	20	24	100	62	777	3.5	0.057
JT	2/8/99	262	9:05	22	242	5	124	1547	6.9	0.090
JT	2/15/99	269	8:05	14	163	3	83	1040	4.6	0.090
JT	2/22/99	276	8:55	10	149	-19	65	814	3.6	0.121
JT	3/2/99	306	9:00	21	132	35	84	1046	4.7	0.064
JT	3/29/99	313	9:10	26	137	54	96	1196	5.3	0.041
JT	4/5/99	319	8:45	23	121	68	95	1184	5.3	0.026
JT	4/12/99	326	9:05	28	130	98	114	1428	6.4	0.013
JT	4/19/99	333	9:30	26	84	97	91	1134	5.0	0.007

bolt tested in lab and retorqued
bolt removed, lead wire resoldered and bolt retorqued

Wires ripped off duct tape and sitting in water for quite a while
Bolts still under water

wires were in the bag but were wet
Right gage still registered an infinite resistance.
Wires were dry and in the bag. Right gage read an infinite resistance.
Rt wire cut and spliced and still read an infinite resistance.

Replaced instrumented bolt with regular bolt.
Replaced w/ instrumented bolt. New Olsets: Lt: 274 Rt: (-2k) 699 New E=28.112x10⁶ kpsi
Wires were dry and in the bag. Measured 2x.

Will replace this next week.

Replaced w/ regular bolt
Replaced w/ instrumented bolt. New Olsets: Lt: 228 Rt: (-2k) 844 New E=28.112x10⁶ kpsi

Re-torqued w/ new torque wrench
wires were dry and in bag

ibid

ibid

posts were wet, sign in shadows

wires were in the bag

Replaced w/ regular bolt permanently

Table 9 Tension and Eccentricity Values For Brevard (2) Sign, Bolt with Flat Washers

Tension vs Time,

Brevard 2nd Sign past Exit 74, Bolt with Spring Washers

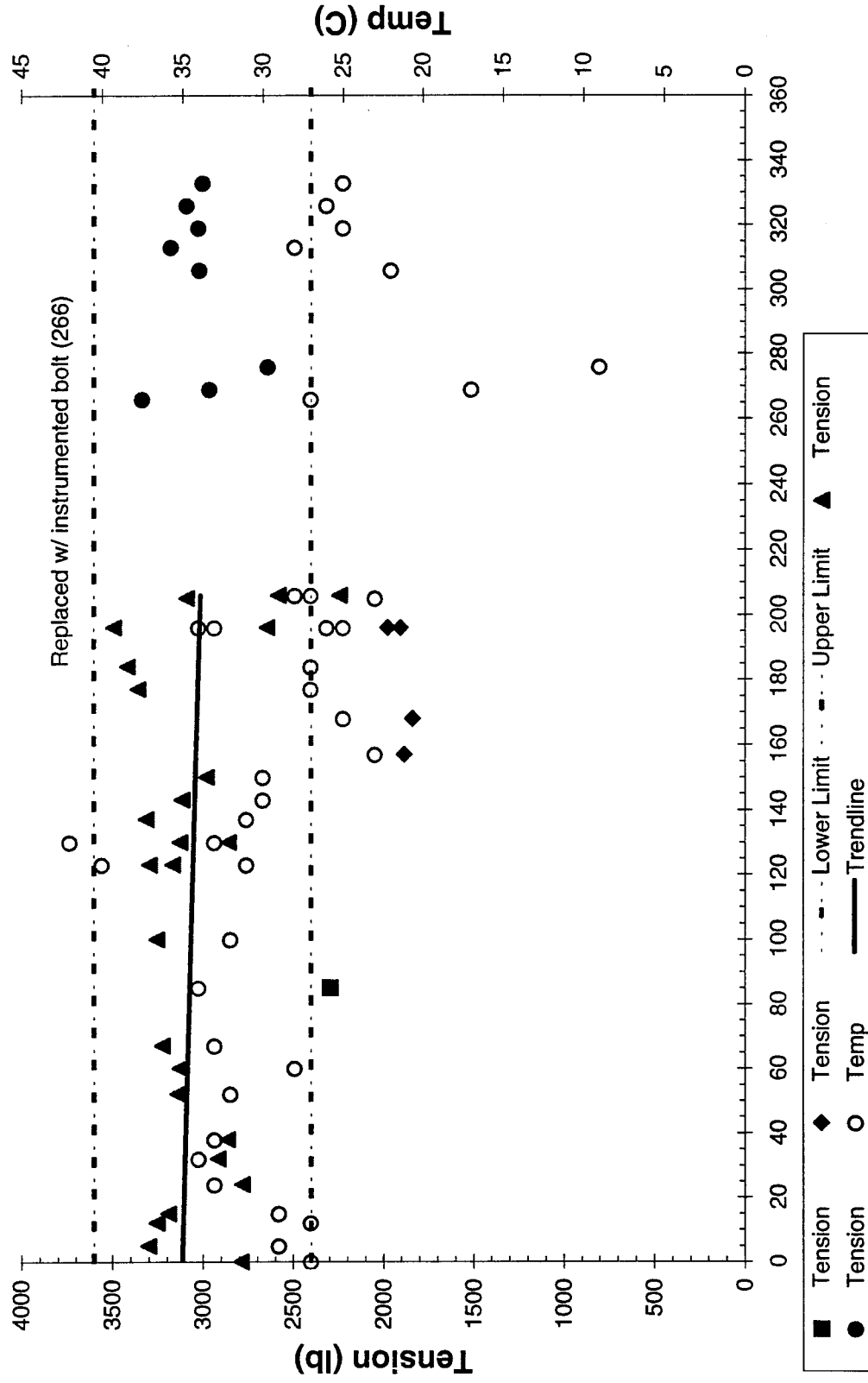
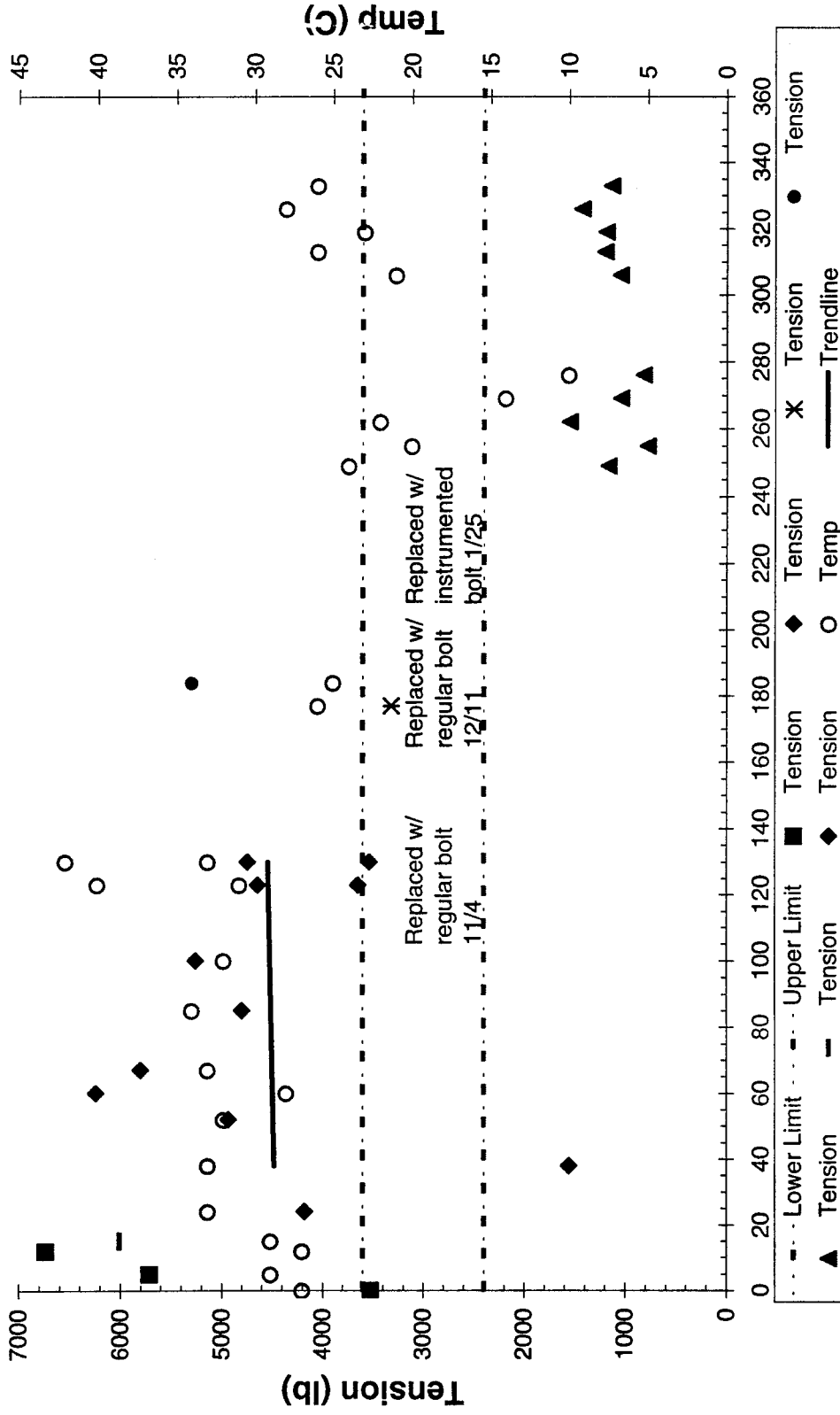


Figure 33 Tension vs Time, Brevard (2) Sign, Bolt with Spring Washers

Tension vs Time

2nd Brevard Sign North of Exit 74, Bolt w/ Flat Washers



Days

Figure 34 Tension vs Time, Brevard (2) Sign, Bolt with Flat Washers

Brevard (1)

The Brevard 1 sign bolts were installed on July 14, 1998 and it they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along I-95, past Exit 74. It is bolted down using 7/8" diameter bolts. Figure 35 shows the location of the sign with respect to I-95.

Tables 10 and 11 list the results of monitoring the bolts from July 14, 1998 to July 15, 1999. Figures 36 and 37 show a plot a plot of tension vs. time for the bolt with the spring washers and the bolt with flat washers.

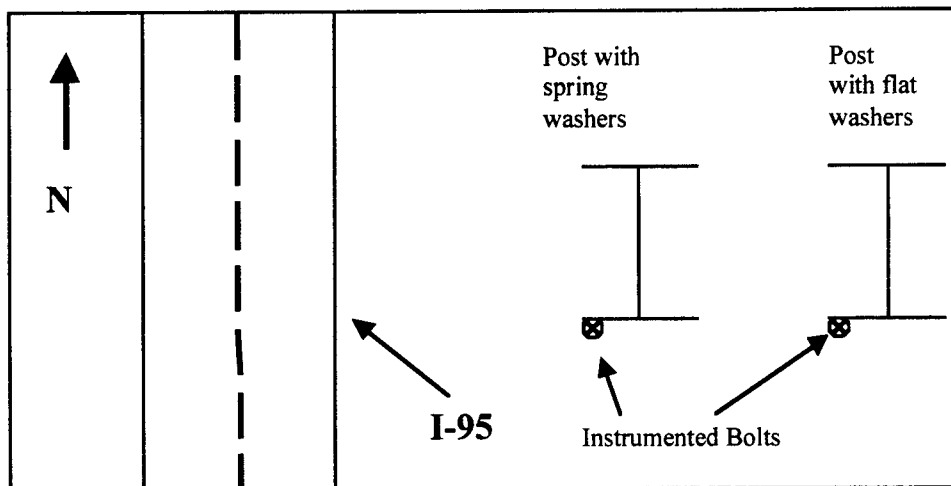


Figure 35 Location of Brevard (1) Sign with respect to I-95

The bolt with spring washers remained in the acceptable range from July 1998 to November 1998 except for one day: September 26 at 3915 lb. and 3749 lb.

The bolt was replaced on November 4, 1998 because the right strain gage became loose. The newly re-instrumented bolt was re-installed on November 20, 1998 along with a new spring washer stack. After that date, the readings were initially above the upper limit of 3600 lb. until February 15, 1999. From then on, the readings were in the allowable range. On June 15, 1999, the wires were found cut. Therefore the readings were interrupted.

The bolt with flat washers was also installed on July 14, 1998. The washers were only able to hold the tension within the acceptable range on July 14 and on July 16. Since then, the readings have always been below the allowable range with a substantial reduction in tension of the bolt. One can notice that negative strain readings were periodically recorded which is reflected in the relatively large eccentricities of the tensions.

The bolt was submerged in water once on February 1, 1999 but it was still possible to get readings that day.

Location: Brevard; first sign past exit 74 going north.

Sign reads: "Highway 520 - 4 miles, Jacksonville - 151 miles"

Description: Green Sign - 19'-6" X 6' X 21' from ground, W10X45 posts, 7/8" bolts

Long Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right	Average	lbs	kN	
		7/14/98			392	59				
SON	7/14/98	0	-	-	352	72	212	3697	16.4	0.072
SON	7/16/98	2	9:00	30	284	55	170	2956	13.1	0.074
SON	7/23/98	9	9:45	32	338	60	199	3470	15.4	0.076
N	8/11/98	27	1:00	36	237	57	147	2563	11.4	0.067
N	8/26/98	42	10:30	35	265	92	179	3113	13.8	0.053
ML	9/19/98	65	10:25	41	267	112	190	3305	14.7	0.045
ML	9/19/98	65	7:10	32	248	156	202	3523	15.7	0.025
ML	9/26/98	72	10:45	32	259	190	225	3915	17.4	0.017
ML	9/26/98	72	3:10	36	254	176	215	3749	16.7	0.020
JT	10/3/98	79	10:32	29	204	176	190	3313	14.7	0.008
JT	10/9/98	85	9:55	32	191	221	206	3592	16.0	0.008
JT	10/16/98	92	9:55	27	199	0				
JT	10/23/98	99	10:03	20						
JT	11/4/98	110	10:25							
JT	11/13/98	119	10:25							
JT	11/20/98	126	9:00	25	355	90	223	3880	17.3	0.065
JT	12/2/98	138	8:50	28	350	90	220	3836	17.1	0.065
		138	11:40	27	355	99	227	3958	17.6	0.062
		138	3:20	26	349	83	216	3767	16.8	0.067
		138	4:20	26	347	84	216	3758	16.7	0.067
JT	12/11/98	147	8:45	22	340	99	220	3828	17.0	0.060
		147	11:35	28	340	110	225	3924	17.5	0.056
		147	3:05	26	340	109	225	3915	17.4	0.056
JT	1/25/99	191	9:30	25	342	112	227	3958	17.6	0.055
JT	2/1/99	197	3:10	21	340	124	232	4046	18.0	0.051
JT	2/8/99	204	8:50	21	300	118	209	3645	16.2	0.048
JT	2/15/99	211	8:50	17	289	100	195	3392	15.1	0.053
JT	2/22/99	218	8:40	12	239	121	180	3139	14.0	0.036
JT	3/22/99	248	8:45	24	265	125	195	3400	15.1	0.039
JT	3/29/99	255	9:00	28	290	116	203	3540	15.7	0.047
JT	4/5/99	261	8:35	35	284	116	200	3488	15.5	0.046
JT	4/12/99	268	8:55	26	262	134	198	3453	15.4	0.035
JT	4/19/99	275	9:20	28	220	114	167	2912	13.0	0.035
JT	4/23/99	279	10:20	32	268	133	201	3496	15.6	0.037
JPP	5/31/99	317	11:30	33	70	274	172	2999	13.3	0.065
JPP	6/15/99	331	11:30							

Wires left out of the bag & exposed

Wires were in the bag and dry.

Wires were dry and in the bag. Flight gage read an infinite resistance

Cut and spliced both wires. Rt gage read infinite resistance. Will replace next week.

Replaced instrumented bolt w/ regular bolt

Still repairing the bolt

Replaced with new instrumented bolt and new spring washer stack.

Wires were dry and in the bag.

ibid

ibid

wires were dry and in the bag.

ibid

ibid

ibid

rust on all washers

ibid

ibid

ibid

ibid

ibid

wires were cut

Table 10 Tension and Eccentricity Values For Brevard (1) Sign, Bolt with Spring Washers

Location: Brevard; first sign past exit 74 going north.

Sign reads: "Highway 520 - 4 miles, Jacksonville - 151 miles"

Description: Green Sign - 19'-6" X 6' X 21' from ground, W10X45 posts, 7/8" bolts

Short Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right	Average	lbs	kN	
			Balance Offset >>		374	337				
SON	7/14/98	0	-	-	-33	337	152	2651	11.8	0.133
SON	7/16/98	2	9:00	30	-50	340	145	2529	11.2	0.147
SON	7/23/98	9	9:45	32	-47	293	123	2145	9.5	0.151
N	8/1/98	27	1:00	36	-73	240	84	1456	6.5	0.205
N	8/26/98	42	10:30	35	32	203	118	2049	9.1	0.080
ML	9/19/98	65	10:25	41	19	198	109	1892	8.4	0.090
ML	9/19/98	65	7:10	32	23	205	114	1988	8.8	0.087
ML	9/26/98	72	10:45	32	8	181	95	1648	7.3	0.100
ML	9/26/98	72	3:10	36	4	176	90	1569	7.0	0.105
JT	10/3/98	79	10:52	29	-4	184	80	1569	7.0	0.114
JT	10/9/98	85	10:05	30	-14	152	69	1203	5.4	0.132
JT	10/16/98	92	10:05	31	-7	136	65	1125	5.0	0.121
JT	10/23/98	99	9:51	21	-20	145	63	1090	4.8	0.144
JT	11/4/98	110	10:15	22	-20	155	68	1177	5.2	0.142
JT	11/13/98	119	10:25	25	-6	150	72	1256	5.6	0.118
JT	11/20/98	126	8:55	25	6	176	91	1587	7.1	0.102
JT	12/2/98	138	8:40	23	0	151	76	1317	5.9	0.109
		138	11:35	27	12	141	77	1394	5.9	0.092
		138	3:15	26	8	137	73	1264	5.6	0.097
		138	4:15	25	12	145	79	1369	6.1	0.093
JT	12/11/98	147	8:40	22	20	126	73	1273	5.7	0.079
		147	11:30	27	28	130	79	1378	6.1	0.071
		147	3:05	25	24	117	71	1229	5.5	0.072
JT	1/25/99	191	9:25	22	9	95	52	907	4.0	0.090
JT	2/1/99	197	3:00	21	26	111	69	1195	5.3	0.068
JT	2/8/99	204	8:45	21	18	123	71	1229	5.5	0.081
JT	2/15/99	211	8:40	15	-24	116	46	802	3.6	0.166
JT	2/22/99	218	8:35	11	-4	78	37	645	2.9	0.121
JT	3/2/99	248	8:40	22	4	138	71	1238	5.5	0.103
JT	3/29/99	255	9:00	26	15	145	80	1395	6.2	0.089
JT	4/5/99	261	8:30	26	17	129	73	1273	5.7	0.084
JT	4/12/99	268	8:50	26	24	88	56	977	4.3	0.063
JT	4/19/99	275	9:15	25	32	130	81	1413	6.3	0.066
JT	4/23/99	279	10:15	29	46	136	91	1587	7.1	0.054
JPP	5/31/99	317	11:30	33	81	123	102	1779	7.9	0.023
JPP	6/15/99	331	11:30	30	57	160	109	1892	8.4	0.052
JPP	7/2/99	348	1:15	30	60	161	111	1927	8.6	0.050
JPP	7/15/99	361	10:10	34	46	120	83	1447	6.4	0.049

*check twice, it is correct

Wires were kept in the plastic bag

Wires were dry and in the bag.

Wires were dry and in the bag. Both readings fluctuated a lot

Wires were dry and in the bag.

Wires were dry and in the bag. Bolts were wet.

Wires were dry and in the bag.

Wires were dry and in the bag.

ibid

ibid

ibid

Wires were dry and in the bag.

bolts were submerged in water

Wires were dry and in the bag.

ibid

ibid

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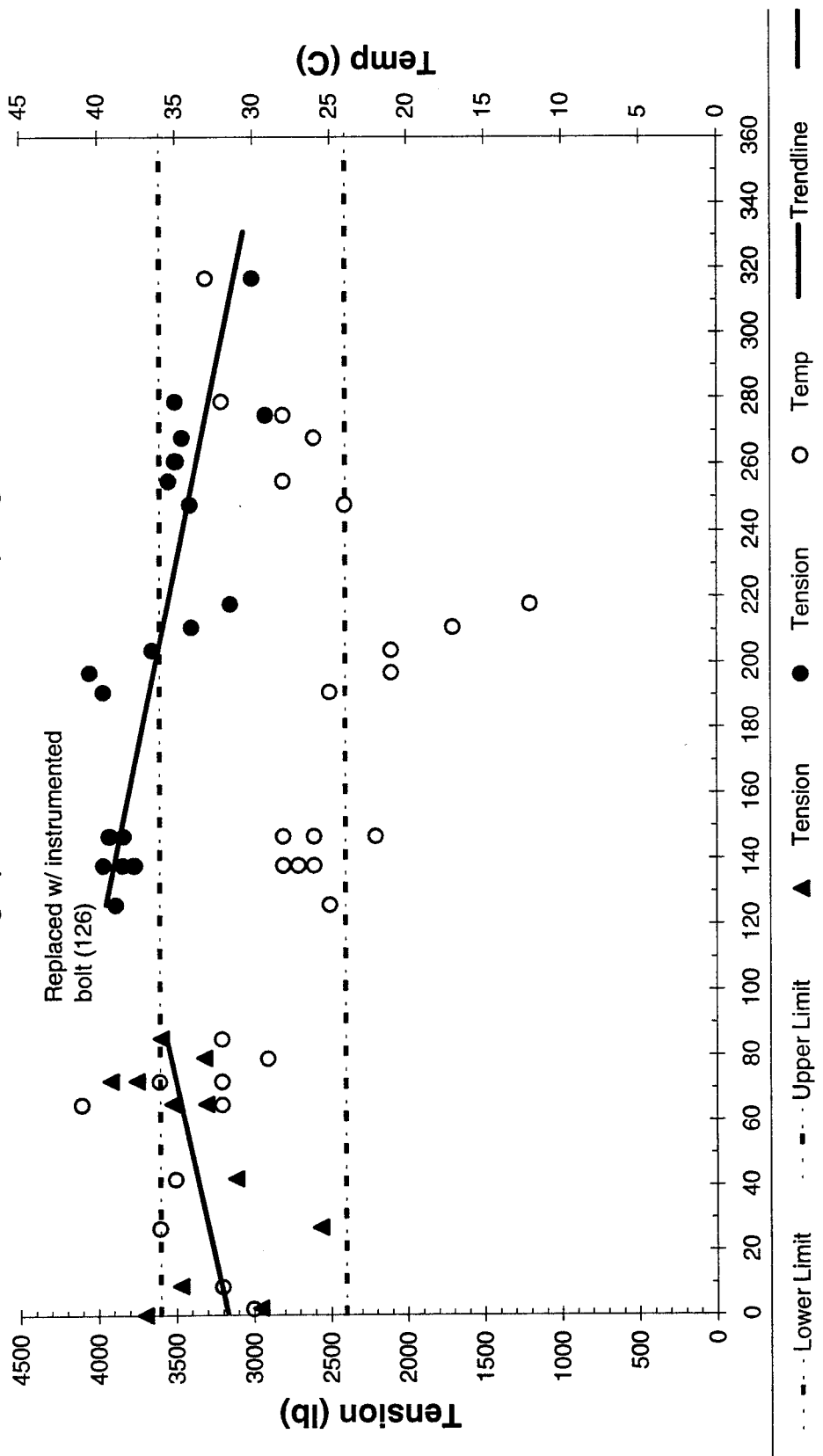
ibid

ibid

Table 11 Tension and Eccentricity Values For Brevard (1) Sign, Bolt with Flat Washers

Tension vs Time

1st Brevard Sign past Exit 74, Bolt w/ Spring Washers



Days

Figure 36 Tension vs Time, Brevard (1) Sign, Bolt with Spring Washers

Tension vs Time

1st Brevard Sign North of Exit 74, Bolt w/ Flat Washers

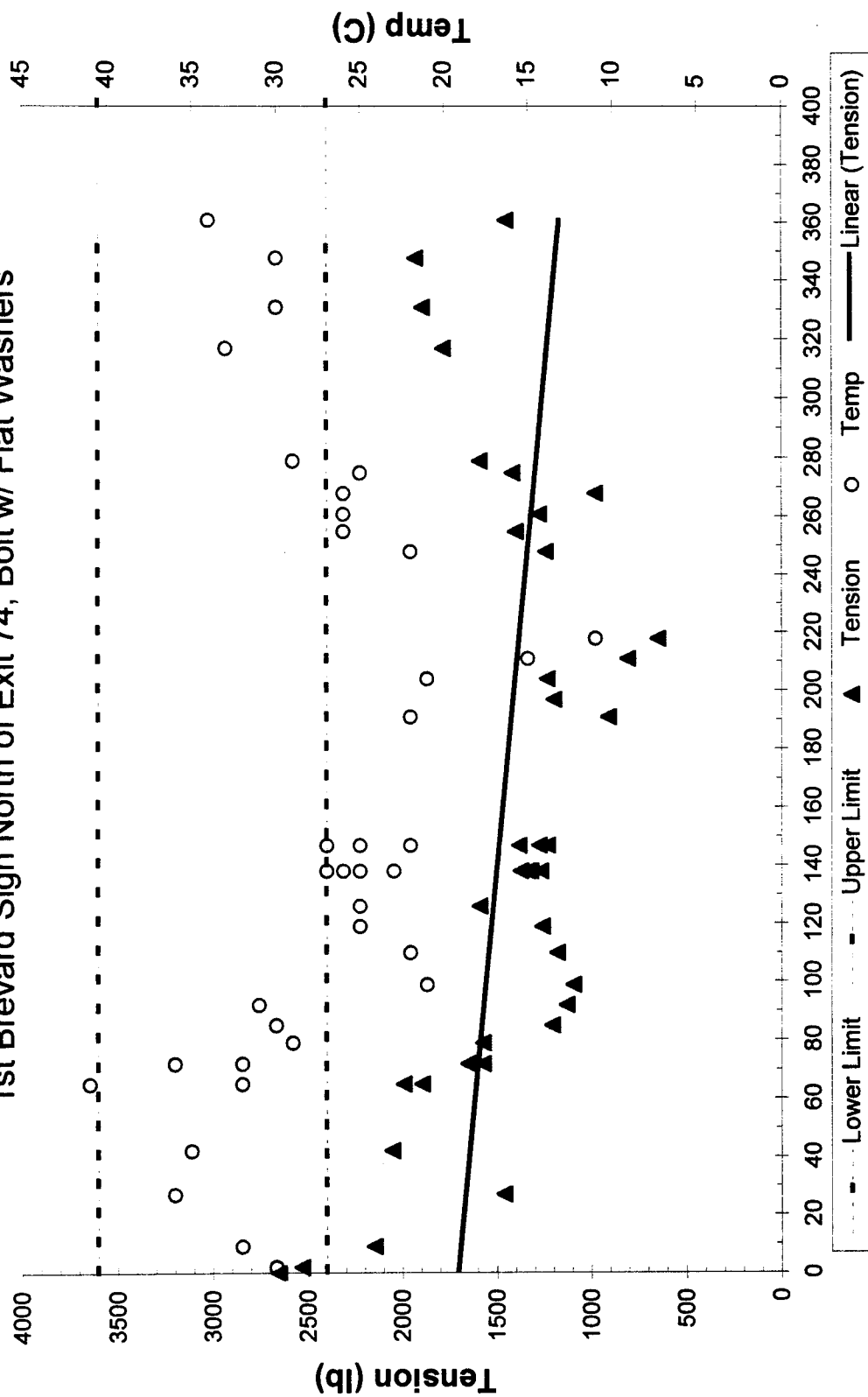


Figure 37 Tension vs Time, Brevard (1) Sign, Bolt with Flat Washers

Sebastian Inlet

The Sebastian Inlet sign bolts were installed on May 15, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along A1A just south of the Sebastian Inlet Bridge. It is bolted down using 3/4" diameter bolts. Figure 38 shows the location of the sign with respect to A1A.

Tables 12 and 13 list the results of monitoring the bolts from May 15, 1998 until June 11, 1999. Figures 41 and 42 show a plot of the tension vs. time the bolt with the spring washers and the bolt with the flat washers.

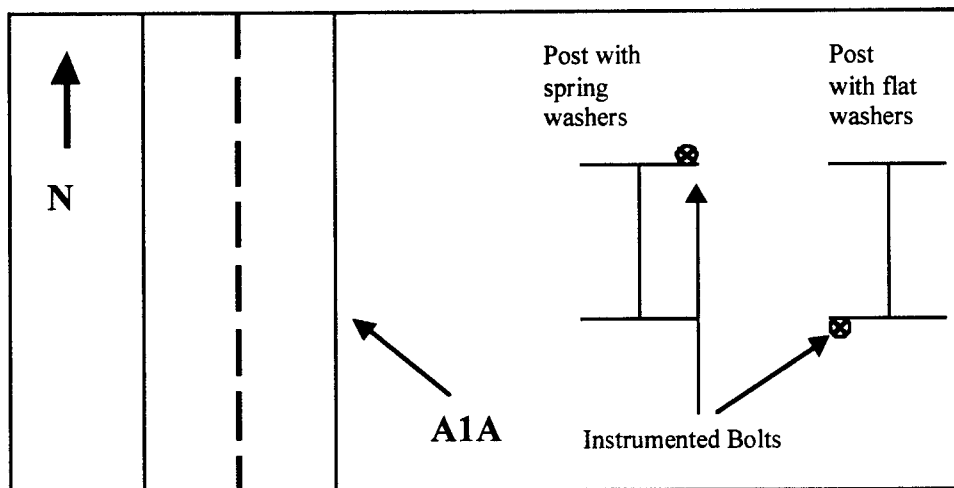


Figure 38 Location of Sebastian Inlet Sign with respect to A1A

The Sebastian Inlet bolt with spring washers was able to maintain the tension within the acceptable range until June 25 with only one reading dipping below the lower limit; on May 27, 1998 at 2146 lb. After that date the tension readings until September 20 were above the upper limit, peaking at 6098 lb. on August 11, 1998.

The wires were ripped off from the bolt head in September. The instrumented bolt was removed on October 21 and was a newly instrumented bolt with a measured modulus of elasticity of 28,074 ksi. was re-installed on December 4, 1998.

The post with the bolt with spring washers was found dislodged on December 9, 1998. It was hit by a car and the base connection of the post broke away. Neither the bolts nor the spring washers were damaged and they were found scattered on the ground. Figures 39 and 40 show

the sign after it was hit by a car. This event, totally unexpected, provided a clear demonstration of the effectiveness of the spring washers. The post separated neatly from the base and as far as we know, no major damage was reported for the car. The sign was re-installed afterwards and since then, the readings were initially within the acceptable range. However the last readings are not reliable, because the bolt was not galvanized. The bolt deteriorated very quickly, and became completely corroded.



Figure 39 Sebastian Sign after it was hit by a car, 1st view

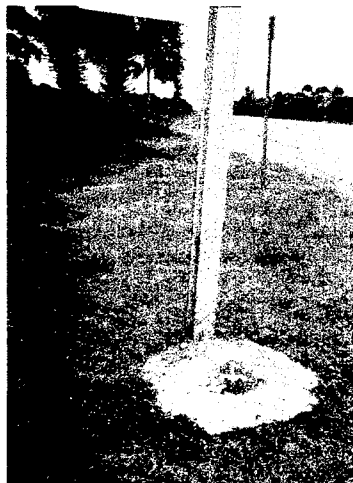


Figure 40 Sebastian Sign after it was hit by a car 2nd view

The bolt with flat washers was able to maintain the tension within the acceptable range until July 22. From September 11 to November 6, the readings were above 3600 lb. and the bolt started to

show erratic behavior. A test to determine if the torque and strains had a linear relationship was performed on November 11 and on November 18. We concluded that the strain gages were faulty so we took the bolt back to the lab to be re-instrumented and re-tested.

The bolt was re-installed on December 4, 1998, with a measured modulus of elasticity of 29,406 ksi. That day's reading was 3774 lb. and has been decreasing until January 29, 1999.

It was suspected that the torque wrench being used may have been inaccurate. A new torque wrench was bought and it was used to re-torque the bolt on February 5, 1999. That day's reading was high at 4300 lb. but went down to 3449 lb. on February 12. No readings were taken on February 19 because the readings were negative numbers in the thousands range. The gages were probably damaged. Subsequent readings were either below or above the allowable range. The bolt was finally removed and brought back to the lab. A tensile test showed a value of 29,276 ksi for the modulus of elasticity. Consequently, the erratic behavior of the bolt could not be attributed directly to a defect of the strain gages.

Location: Sebastian Inlet. Directly after the bridge on A1A going south.

Sign reads: "Sebastian Inlet State Recreation Area."

Description: Brown Sign - 15.5' X 5' X 9' from ground, W8X18 posts

Long Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right	Average	lbs	kN	
		5/15/98			479	494				
ML	5/15/98	0	-	29	370	47	209	2671	11.9	0.073
ML	5/20/98	5	-	34	346	45	196	2505	11.1	0.072
ML	5/27/98	12	-	28	296	39	168	2146	9.5	0.072
SON	6/9/98	24	3:40	33	357	74	216	2761	12.3	0.062
SON	6/17/98	32	12:15	36	369	111	240	3075	13.7	0.050
SON	6/25/98	40	11:10	31	378	141	260	3325	14.8	0.043
SON	7/9/98	54	11:00	34	412	246	329	4215	18.7	0.024
SON	7/16/98	61	11:30	35	463	280	372	4760	21.2	0.023
SON	7/22/98	67	11:00	32	468	326	397	5086	22.6	0.017
N	8/11/98	86	11:45	34	502	450	476	6098	27.1	0.005
N	8/29/98	101	8:00	32	469	335	402	5150	22.9	0.016
ML	9/20/98	125	9:15	31	506	328	417	5343	23.8	0.020
ML	9/26/98	131								
JT	10/2/98	137								
JT	10/7/98	142								
JT	10/14/98	149								
JT	10/21/98	156								
JT	11/6/98	171	5:10							
JT	11/11/98	176	2:30	31	239	184	212	3148	14.0	0.012
JT	11/18/98	183	1:30	31	160	-200	-20	-298	-1.3	-0.844
JT	12/4/98	189	1:15	35	382	46	214	2654	11.8	0.074
JT	12/9/98	204	12:00							
JT	12/29/98	247	4:15	26	-586	973	194	2400	10.7	0.378
JT	1/29/99	254	12:30	29	275	215	245	3039	13.5	0.011
JT	2/5/99	260	1:30	28	205	164	230	2846	12.7	0.027
JT	2/12/99	267	9:05	27	272	140	206	2555	11.4	0.030
JT	2/19/99	274	8:40	20	208	128	168	2084	9.3	0.022
JT	3/26/99	311	12:15	30	279	159	219	2716	12.1	0.026
JT	4/2/99	317	12:00	31	261	167	214	2654	11.8	0.021
JT	4/10/99	325	10:05	29	233	75	154	1910	8.5	0.048
JT	4/16/99	331	12:15	32	334	156	245	3039	13.5	0.034
JT	4/23/99	338	9:10	33	418	180	299	3708	16.5	0.037
JPP	5/25/99	370	15:00	34	464	218	341	4229	18.8	0.034
JPP	6/2/99	377	13:00	32	460	160	310	3845	17.1	0.045
JPP	6/11/99	386	1:00	28	828	488	658	8161	36.3	0.024

Wires ripped off the bolt
Did not proceed. Wires were supposedly ripped off.
Wires ripped off. Tried to replace bolt, washer was stuck; need help in replacing the damaged bolt.
Wires were still ripped off.
Replaced instrumented bolt with a regular bolt.
Replaced regular bolt with instrumented bolt Lt: 193 Rt: 463
Replaced w/ new bolt, Retorqued w/ new offsets: Lt: 93 Rt: 270; New E=33,691x10⁶ kpsi
Rt reading changed a lot. Lt took a while to stabilize. Wires were dry and in the bag.
Replaced w/ instrumented bolt. New Offsets: Lt: 479 Rt: 494 New E=28,074x10⁶ kpsi
Post was dislodged w/ bolts detached. Took back the instrumented bolt
Re-installed the instrumented bolt
Re-installed & re-aligned the instrumented bolt
Re-installed the rest of the bolts & re-torqued the instrumented bolt
wires were dry and in the bag
bkd
rusting on all washers, bolt w/ instrumented bolt is rusted.
wires were dry and in the bag
bkd
bkd
bkd
bkd
bolt completely rusted

Table 12 Tension and Eccentricity Values For Sebastian Inlet Sign, Bolt with Spring Washers

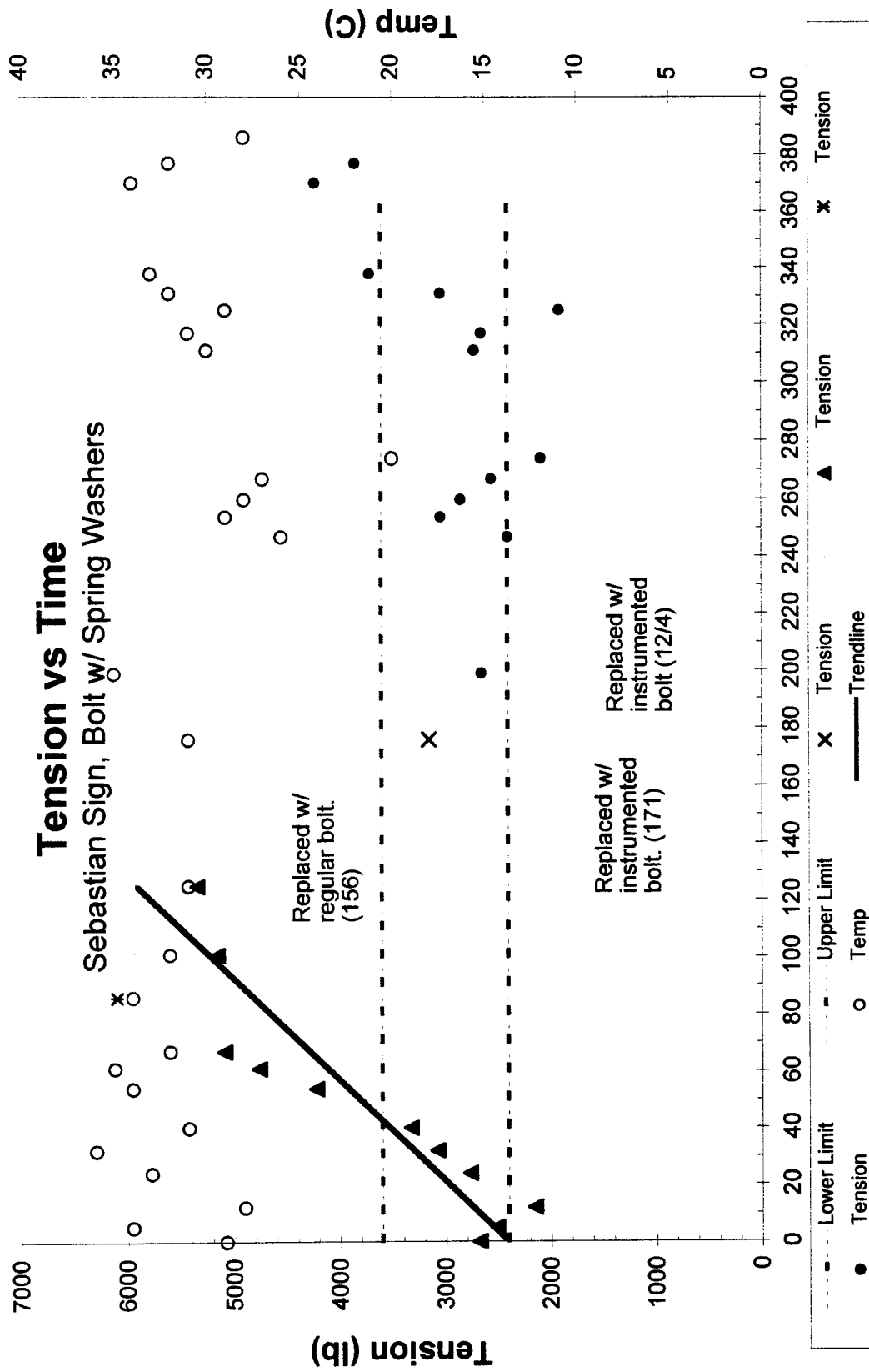
Location: Sebastian Inlet; Directly after the bridge on A1A going south.
 Sign reads: "Sebastian Inlet State Recreation Area."
 Description: Brown Sign - 15.5' X 5' X 9' from ground, W8X18 posts

Short Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccent. (in)
					Left	Right	Average	lbs	kN	
					Balance Offset >>					
	5/15/98	0	-	29	282	821				
ML	5/15/98	0	-	29	498	160	329.0	4215	18.7	0.048
ML	5/20/98	5	-	34	448	109	278.5	3568	15.9	0.057
ML	5/27/98	12	-	28	441	104	272.5	3491	15.5	0.058
SON	6/9/98	24	3:40	33	430	98	264.0	3382	15.0	0.059
SON	6/17/98	32	12:15	36	431	103	267.0	3421	15.2	0.058
SON	6/25/98	40	11:10	31	418	98	258.0	3305	14.7	0.058
SON	7/9/98	54	11:00	34	421	106	263.5	3376	15.0	0.056
SON	7/16/98	61	11:30	35	411	102	256.5	3286	14.6	0.056
SON	7/22/98	67	11:00	32	445	114	279.5	3581	15.9	0.056
N	8/11/98	86	11:45	34	473	132	302.5	3876	17.2	0.053
N	8/26/98	101	8:00	32	450	135	292.5	3747	16.7	0.050
ML	9/20/98	125	9:15	31	496	129	312.5	4004	17.8	0.055
ML	9/26/98	131	8:35	31	542	124	333.0	4266	19.0	0.059
ML	9/26/98	131	12:55	41	565	133	349.0	4471	19.9	0.058
JT	10/2/98	137								
JT	10/7/98	142	3:00	43	542	111	326.5	4183	18.6	0.062
JT	10/14/98	149	1:25	36	536	112	324.0	4151	18.5	0.061
JT	10/21/98	156	3:50	29	550	287	418.5	5362	23.9	0.029
JT	11/6/98	171	4:50	20	555	421	488.5	6259	27.8	0.013
JT	11/11/98	176	2:50	32	330	248	289.0	3703	16.5	0.013
JT	11/18/98	183	2:50	35	526	539	532.5	6822	30.3	0.001
JT	12/4/98	199	2:00	34	81	500	290.5	3774	16.8	0.068
JT	12/9/98	204	12:10	35	17	565	291.0	3780	16.8	0.088
JT	12/22/98	247	4:25	26	118	112	115.0	1494	6.6	0.002
JT	1/23/99	254	12:50	31	133	59	96.0	1247	5.5	0.036
JT	2/5/99	260	1:45	29	302	360	331.0	4300	19.1	0.008
JT	2/12/99	267	8:10	27	271	260	265.5	3449	15.3	0.002
JT	2/19/99	274	8:45	20						
JT	3/26/99	311	12:20	29	227	-74	76.5	994	4.4	0.184
JT	4/2/99	317	12:05	35	261	45	153.0	1988	8.8	0.066
JT	4/10/99	325	10:10	30	175	509	342.0	4443	19.8	0.046
JT	4/16/99	331	12:20	33	219	450	334.5	4346	19.3	0.032

Did not proceed. Wires were supposedly ripped off.
 Wires were in the bag.
 Wires were in the bag.
 Wires were in the bag.
 Bag was ripped off the post.
 Wires were dry and in the bag. ITT 2x. Replaced instrumented bolt w/ regular bolt.
 Replaced w/ instrumented bolt. New Offsets: Lt: 282 Rt: 821 New E=29,406x10⁻⁶ kpsi
 Wires were dry and in the bag.
 Re-torqued using a new torque wrench.
 Wires were dry and in the bag
 Bolt was wet. Got big (-) readings
 Wires were dry and in the bag.
 Replaced w/ regular bolt permanently

Table 13 Tension and Eccentricity Values For Sebastian Inlet Sign, Bolt with Flat Washers



Days

Figure 41 Tension vs Time, Sebastian Inlet Sign, Bolt with Spring Washers

Tension vs Time Sebastian Sign, Bolt w/ Flat Washers

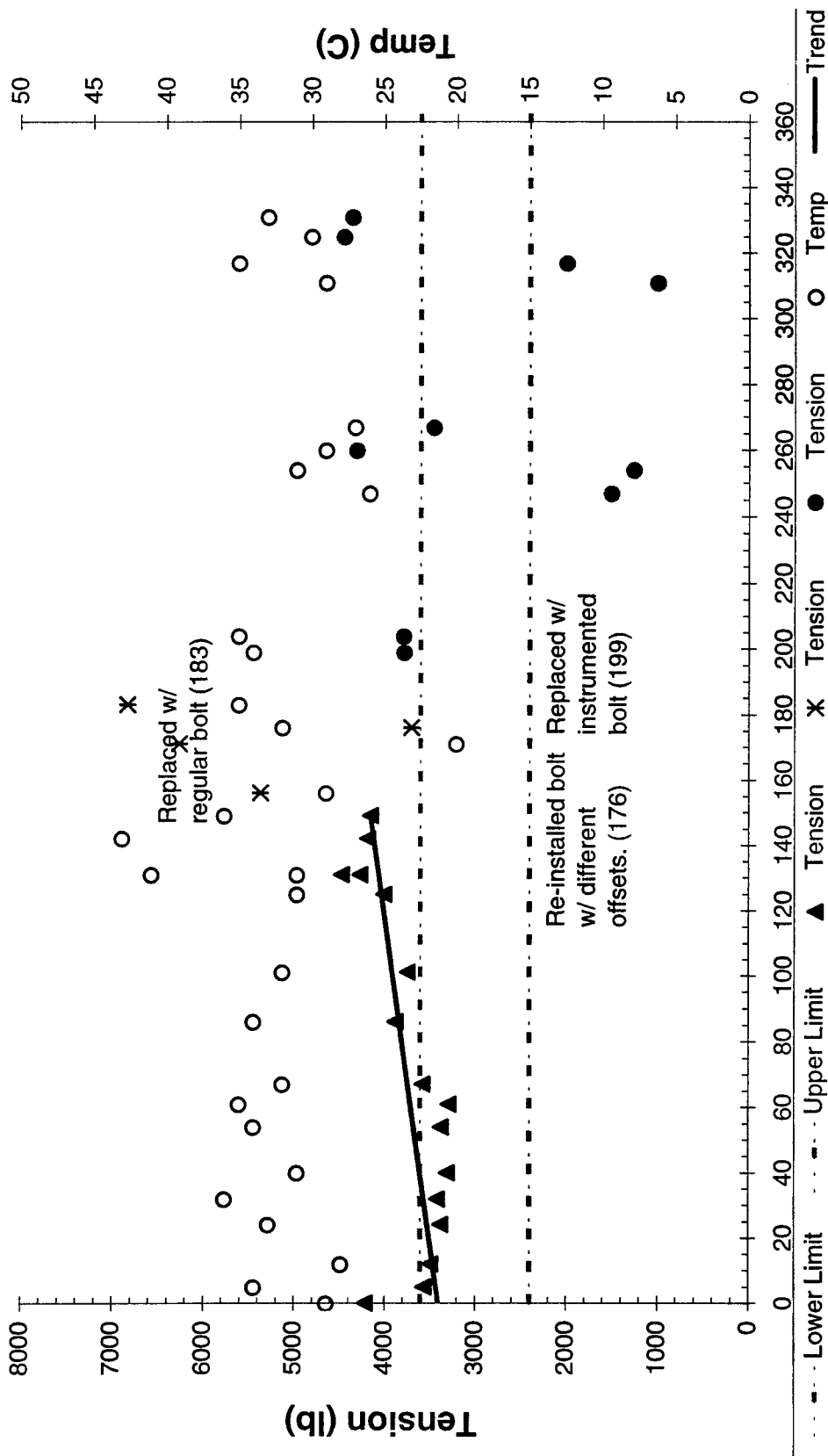


Figure 42 Tension vs Time, Sebastian Inlet Sign, Bolt with Flat Washers

Indian River

The Indian River sign bolts were installed on May 15, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located southbound along I-95 just south of the 146-mile marker. It is bolted down using 3/4" diameter bolts. Figure 43 shows the location of the sign with respect to I-95.

Tables 14 and 15 list the results of monitoring the bolt from May 15, 1998 until July 6, 1999. Figures 44 and 45 show a plot of the tension vs. time for the bolt with the spring washers and the bolt with flat washers.

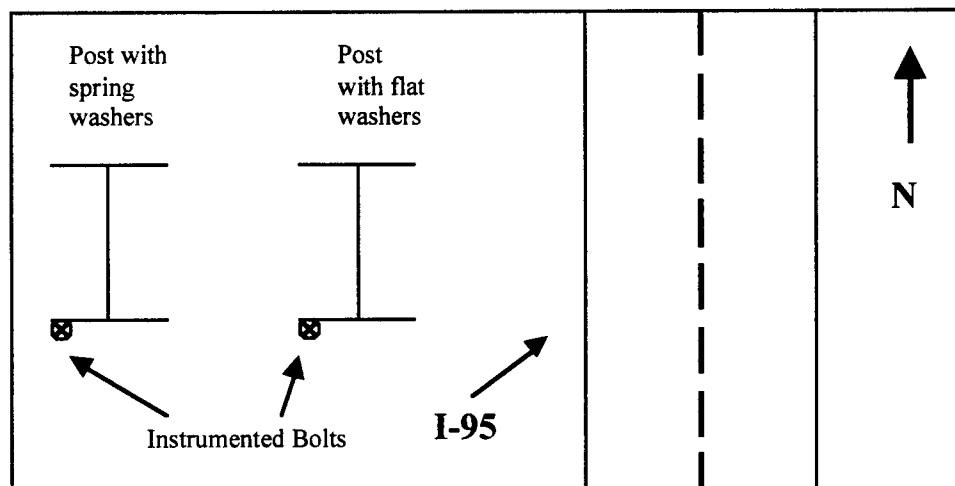


Figure 43 Location of Indian River Sign with respect to I-95

For the Indian River bolt with spring washers, the readings from May 15, 1998 through June 9, 1998 were all under the lower limit of 2400 lb. The bolt was then re-installed and it maintained the tension within the acceptable range (2400 lb. to 3600 lb.) from June 1998 through early December 1998. From June 17, 1998 through January 18, 1999 the left strain gage read a negative strain indicating that the bolt was subjected to a combination of tension and bending. This is reflected in the big eccentricities in the readings.

The initial readings taken during January 1999 showed that the tension increased, so we brought the bolt back to have the strain gages replaced. After replacing the strain gages, the spring washers were able to maintain the tension within the acceptable range until this date.

The Indian River bolt with flat washers was not able to maintain tension within the acceptable range. The eccentricities from May 15, 1998 through February 19, 1999 were small which meant that the bolt was not subjected to any significant bending.

This bolt has been re-installed four times. It was removed on June 17 because that day's readings were too high. The bolt was re-installed in June 25, 1998 and the readings had been below 2400 lb. up to August 26. After that date, the readings were well above the upper limit. It was replaced on October 21 and a new one was re-installed on November 6. The reading on that day was high while the following reading on November 11 was low. The bolt was re-instrumented and re-installed on December 9 with a modulus of elasticity of 28,706 ksi. The readings after that date were low until January 18, 1999 when the wires were ripped off. A newly instrumented bolt was re-installed on February 5, 1999 with a measured modulus of elasticity of 28,120 ksi. The readings since then have been low up to July 6, 1999.

Location: Indian River; I-95 South of Vero Beach (mile post 146)

Sign reads: "Indrio Rd. 8, Miami 146."

Description: Green Sign - 14' X 5.5' X 10' from ground, WBX24 posts

Short Bolt

Operator	Date	# of Days After	Time	Temp °C	Strain Reading (µε)	Bolt tension lbs	Bolt tension kN	Eccent. (in)
					Left Right Average			
		5/15/98			-24/796			
ML	5/15/98	0	-	29	226	126	176	0.027
ML	5/20/98	5	-	28	790	117	454	0.070
ML	5/27/98	12	-	27	366	116	241	0.049
SON	6/9/98	24	12:40	40	70	123	97	0.026
SON	6/17/98	32	10:00	35	700	120	410	0.066
SON	6/25/98	40	9:00	28	149	112	131	0.013
SON	7/9/98	54	9:00	32	133	160	147	0.009
SON	7/16/98	61	9:45	32	133	159	146	0.008
SON	7/22/98	67	9:00	25	167	152	160	0.004
N	8/11/98	86	9:30	33	162	155	159	0.002
N	8/26/98	101	8:45	30	163	154	159	0.003
ML	9/26/98	131	9:30	42	859	568	714	0.019
ML	9/26/98	131	1:45	41	846	582	714	0.017
JT	10/2/98	137	3:05	34	874	575	725	0.019
JT	10/7/98	142	10:38	37	845	567	706	0.018
JT	10/14/98	149	10:10	30	830	552	691	0.019
JT	10/21/98	156	10:30					
JT	11/6/98	171	2:10	30	49	774	412	0.083
JT	11/11/98	176	10:45	34	95	63	79	0.019
JT	11/18/98	183	9:30					
JT	12/4/98	189	9:15					
JT	12/9/98	204	9:00	20	83	70	77	0.008
JT	12/14/98	209	9:10	20	62	44	53	0.016
		209	11:00	25	70	52	61	0.014
		209	12:00	23	82	49	66	0.024
JT	1/18/99	243	9:55					
JT	1/29/99	254	9:20					
JT	2/5/99	260	9:25	27	18	336	177	0.084
JT	2/12/99	267	11:55	35	16	326	171	0.085
JT	2/19/99	274	10:40	28	11	293	152	0.087
JT	3/26/99	311	9:10	31	14	284	149	0.085
JT	4/2/99	317	9:10	33	47	289	168	0.068
JT	4/10/99	325	11:50	35	21	307	164	0.062
JT	4/16/99	331	9:00	30	20	260	140	0.080
JT	4/23/99	338	11:40	37	28	298	163	0.078
JPP	6/2/99	377	11:30	33	50	300	175	0.067
JPP	6/11/99	386	1:00	28	35	265	150	0.072
JPP	7/6/99	411	7:15	30	-79	257	89	0.177

bolt removed and re-instrumented (bolt very sticky, a lot of friction when retorqued)

Wires were in the bag.

Replaced instrumented bolt with a regular bolt.

Replaced regular bolt with an instrumented bolt. Lt: 78 Rt (490)

Tension was low. Torqued again and average stayed roughly the same.

Replaced instrumented bolt with short bolt.

Have not replaced the regular bolt with an instrumented bolt yet.

Replaced regular bolt with an instrumented bolt. Lt: 8 Rt (-24)/845, New E=28.706x100kpsi

Wires were in the bag.

Wires were ripped off. Replaced with regular bolt.

Was not able to re-install instrumented bolt. After testing, E=25.796 (too low)

Reinstalled inst. bolt w new wrench. Lt: (-24)/796 Rt: (-24)/477, New E=26.121x100kpsi

Wires were dry and in the bag

Table 15 Tension and Eccentricity Values For Indian River Sign, Bolt with Flat Washers

Tension vs Time

Indian River Sign, Bolt w/ Spring Washers

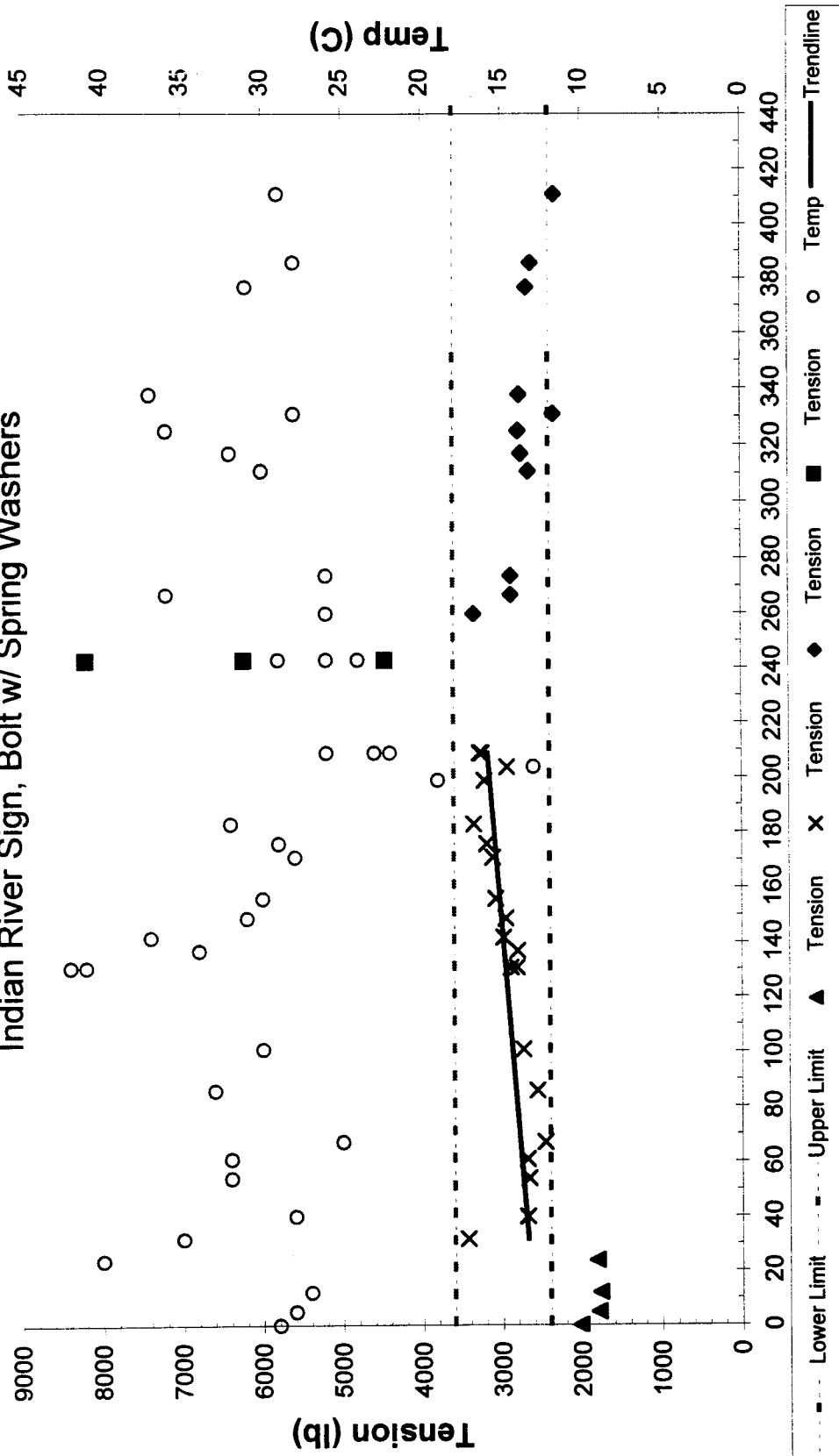
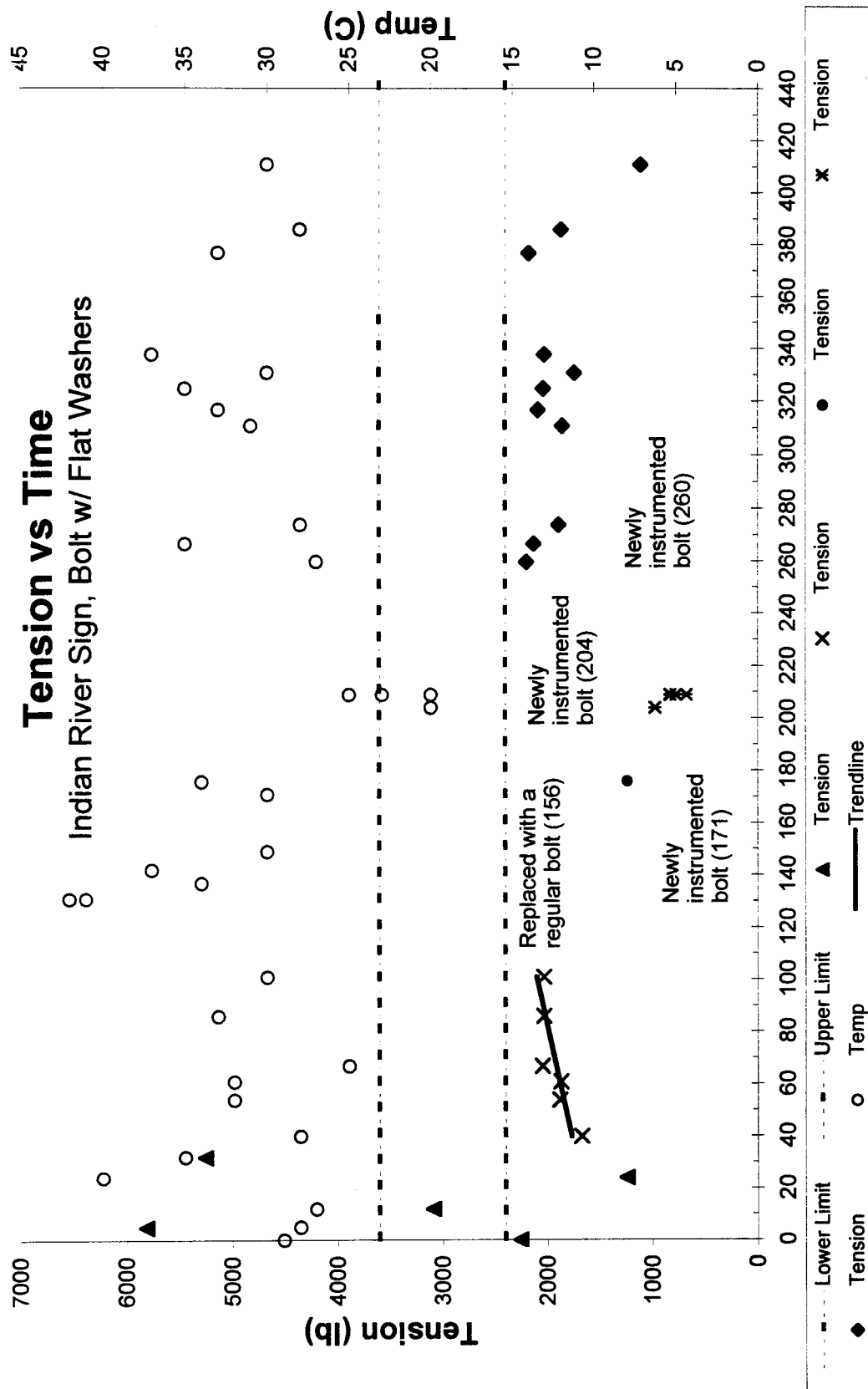


Figure 44 Tension vs Time, Indian River Sign, Bolt with Spring Washers



Days
Figure 45 Tension vs Time, Indian River Sign, Bolt with Flat Washers

Martin County

The Martin County sign bolts were installed on May 15, 1998 and they have been monitored ever since. Different students have been taking readings ever since they were installed. The sign is located northbound along I-95 just south of the Exit 62. It is bolted down using 3/4" diameter bolts. Figure 46 shows the location of the sign with respect to I-95.

Tables 16 and 17 list the results of monitoring the bolts from May 15, 1998 until April 16, 1999. Figures 47 and 48 show a plot of the tension vs. time for the bolt with the spring washers and the bolt with flat washers.

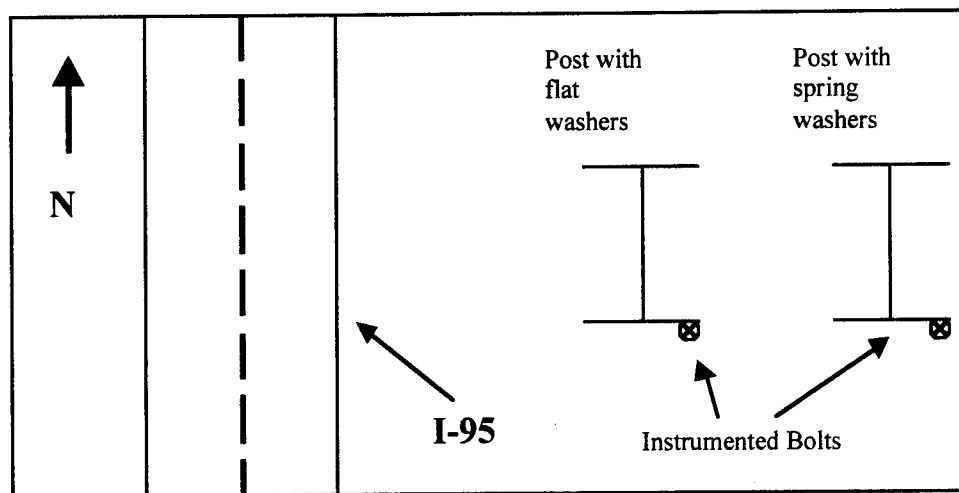


Figure 46 Location of Martin County Sign with respect to I-95

The Martin County bolt with spring washers was able to maintain the tension close to the acceptable range until August 8. It was submerged under water for at least a day on August 11 after which on August 26, the tension reading was 3786 lb. It was again submerged under water on September 10, 1998. From October 2 to October 21, 1998, the tension readings ranged from 4638 lb. to 4894 lb. Again, the bolt was submerged in water on November 6, 1998.

On November 11, 1998, a test was performed to determine if the torque and the strains had a linear relationship and check if the strain gages were working properly. Another test was performed on November 18 and the torque and strain registered a non-linear relationship. Thus we concluded from the tests that the bolt had to be replaced. The bolt was taken back to the lab to be re-instrumented and re-tested.

The newly instrumented bolt was re-installed on December 4, 1998 with a measured modulus of elasticity of 28,664 ksi. Since then the tension readings were out of the acceptable range on four occasions, two of which were over the 5000 lb. Mark. On April 16, the reading was abnormally high, and the bolt was removed. A tensile test in the lab yielded a value of 30,054 ksi for the modulus of elasticity, a 5% increase over the initial value measured before installation in the field.

The bolt with flat washers was able to maintain the tension within the acceptable range until August 26 even though the bolt was submerged in water on August 10 and 11. The bolts were again submerged in water on September 7. In between those dates, a reading was attempted; however, the right gage read an infinite resistance, which prevented a reading to be taken. The readings fluctuated from 1826 lb. on October 14 to 4683 lb. on October 21.

The bolts were again submerged in water on November 6 and 11. On November 18, the right gage was shorted out and so the bolt was taken back to the lab. The bolt was re-installed on December 4, 1998 with a measured modulus of elasticity of 29,687 ksi. Since then, the readings fluctuated with a downward trend, until the bolt was removed on April 10, 1999. A tensile test in the lab yielded a value of 31,912 ksi for the modulus of elasticity, a 9% increase over the initial value measured before installation in the field.

Location: Martin; After mile post 109 going north.

Sign reads "Exit 62, 714, 714, 1/2 mile."

Descriptor Green Sign - 10' X 10' X 12' from ground, W8X24 posts

Long Bolt

Operator	Date	# of Days	Time	Temp °C	Strain Reading (µε)			Bolt tension		Eccentricity (in)
		After	Balance Offset >>		Left	Right	Average	lbs	kN	
ML	5/15/98	0	-	32	268	211	240	3068	13.6	0.011
ML	5/20/98	5	-	30	350	195	273	3491	15.5	0.027
ML	5/27/98	12	-	27	358	186	272	3485	15.5	0.030
SON	6/9/98	24	-	35	396	205	301	3850	17.1	0.030
SON	6/17/98	32	11:00	37	412	205	309	3952	17.6	0.031
SON	6/25/98	40	10:00	34	402	189	296	3786	16.8	0.034
SON	7/9/98	54	10:00	35	419	198	309	3952	17.6	0.034
SON	7/16/98	61	10:30	34	427	193	310	3972	17.7	0.035
SON	7/22/98	67	9:50	30	393	186	290	3709	16.5	0.034
N	8/11/98	86								
N	8/26/98	101	9:30	30	399	192	296	3786	16.8	0.033
ML	9/10/98	115	1:29							
ML	9/10/98	115	7:34							
JT	10/2/98	137	4:45	34	507	223	365	4676	20.8	0.036
JT	10/7/98	142	12:20		506	218	362	4638	20.6	0.037
JT	10/14/98	149	11:25	32	505	220	363	4644	20.7	0.037
JT	10/21/98	156	11:25	35	530	234	382	4894	21.8	0.036
JT	11/6/98	171								
JT	11/11/98	176	12:00	34	81	470	276	3530	15.7	0.066
JT	11/19/98	183	10:40	35						
JT	12/4/98	199	10:15	25	217	206	212	2678	11.9	0.002
JT	12/9/98	204	10:10	35	264	385	325	4109	18.3	0.017
JT	12/14/98	209	10:10	24	230	312	271	3432	15.3	0.014
JT	1/18/99	243	11:00	31	375	203	289	3660	16.3	0.028
JT	1/29/99	254	10:20	31	357	196	277	3501	15.6	0.027
JT	2/5/99	260	10:45	33	493	321	407	5154	22.9	0.020
JT	2/12/99	267	12:50	30	369	169	269	3406	15.2	0.035
JT	2/19/99	274	11:35	31	573	341	457	5787	25.7	0.024
JT	3/26/99	311	10:10	30	409	67	238	3014	13.4	0.067
JT	4/2/99	317	10:00	33	459	73	266	3368	15.0	0.068
JT	4/10/99	325	12:40	36	452	58	255	3229	14.4	0.072
JT	4/16/99	331	10:05	30	691	313	502	6357	28.3	0.035

Sign Bolts under water

Sign Bolts under water

Bolts unaccessible due to muddy conditions

Wires were in the bag
Wires were in the bag. Was not able to take temperature.
left the thermocouple at the Indian River site

Wires were in the bag

Wires were in the bag

Bolts were totally submerged

ITT. Re-installed same bolt & washer with new offsets: Lt: 236 Rt: 114

ITT. Non-linear results. Replaced instrumented bolt with regular one.

Replaced with instrumented bolt. New Offsets: Lt: 210 Rt: 118.

New E = 28,664x10⁶ kpsi

Wires were in the bag

Wires were in the bag

Wires were in the bag

Wires were in the bag

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Wires were in the bag

Table 16 Tension and Eccentricity Values For Martin County Sign, Bolt with Spring Washers

Location: Martin; After mile post 109 going north.

Sign reads "Exit 62, 714, 714, 1/2 mile."

Descriptor Green Sign - 10' X 10' X 12' from ground, WBX24 posts

Short Bolt

Operator	Date	# of Days	Time	Temp	Strain Reading (µε)			Bolt tension		Eccent.
		After		°C	Left	Right	Average	lbs	kN	(in)
		5/15/98			298	208				
ML	5/15/98	0	-	32	280	316	298	3818	17.0	0.006
ML	5/20/98	5	-	30	240	270	255	3267	14.5	0.006
ML	5/27/98	12	-	27	229	268	249	3184	14.2	0.007
SON	6/9/98	24	2:00	35	230	284	257	3293	14.6	0.010
SON	6/17/98	32	11:00	37	217	283	250	3203	14.2	0.012
SON	6/25/98	40	10:00	34	212	274	243	3113	13.8	0.012
SON	7/9/98	54	10:00	35	204	275	240	3068	13.6	0.014
SON	7/16/98	61	10:30	34	213	282	248	3171	14.1	0.013
SON	7/22/98	67	9:50	30	202	285	244	3120	13.9	0.016
N	8/11/98	86								
N	8/26/98	101	8:30	30	220	292	256	3280	14.6	0.013
ML	9/10/98	115	1:30							
ML	9/10/98	115	7:34							
JT	10/2/98	137	4:55		295					
JT	10/7/98	142	12:30		Bolts were inaccessible, they were totally submerged.					
JT	10/14/98	149	11:35	33	285	0	143	1826	8.1	0.094
JT	10/21/98	156	11:30	34	292	439	366	4683	20.8	0.019
JT	11/02/98	171								
JT	11/11/98	176	11:55							
JT	11/19/98	183	11:10							
JT	12/4/98	199	10:45	29	136	394	265	3476	15.5	0.048
JT	12/9/98	204	10:15	34	72	648	360	4722	21.0	0.075
JT	12/14/98	209	10:15	23	101	460	281	3679	16.4	0.060
JT	1/18/99	243	11:05	31	96	218	157	2059	9.2	0.036
JT	1/29/99	254	10:25	30	36	176	106	1390	6.2	0.062
JT	2/5/99	260	10:55	32	29	231	130	1705	7.6	0.073
JT	2/12/99	267	12:55	35	42	132	87	1141	5.1	0.048
JT	2/19/99	274	11:40	31	9	590	300	3928	17.5	0.091
JT	3/26/99	311	10:15	32	43	4	24	308	1.4	0.078
JT	4/2/99	317	10:05	35	52	-30	11	144	0.6	0.349
JT	4/10/99	325	12:45	36	51	-94	-22	-282	-1.3	-0.316

Sign Bolts under water

Sign Bolts under water

Bolts inaccessible due to muddy conditions.

Right gage was possibly shorted out. It read an infinite resistance

Wires were in dry and in the bag. Right gage read a resistance of 25 ohms.

Wires were in dry and in the bag. Cut and spliced both wires

Right gage initially 439 then it fluctuated.

Bolts were totally submerged.

Bolts were totally submerged.

Wires were wet. Rt Gage was shorted out. Replaced with regular bolt.

Replaced with instrumented bolt. New Offsets: Lt: 298 Rt: 208.

New $E = 29.687 \times 10^6 \text{ kpsi}$

wires were dry and in the bag

ibid

ibid

ibid

ibid

ibid

ibid

ibid

ibid

ibid

ibid

ibid

ibid

Table 17 Tension and Eccentricity Values For Martin County Sign, Bolt with Flat Washers

Tension vs Time Martin Sign, Bolt w/ Spring Washers

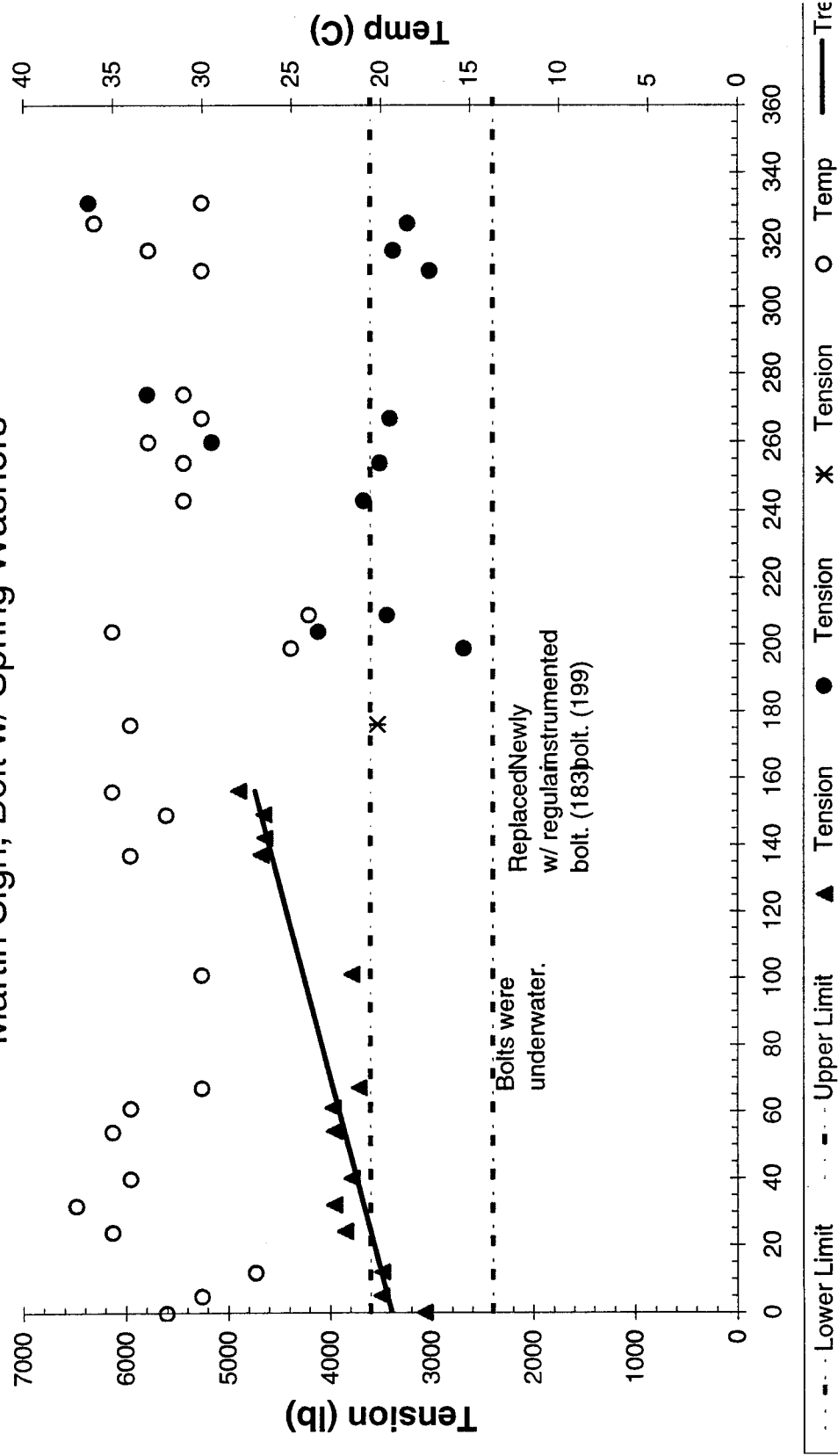


Figure 47 Tension vs Time, Martin County Sign, Bolt with Spring Washers

Tension vs Time Martin Sign, Bolt w/ Flat Washers

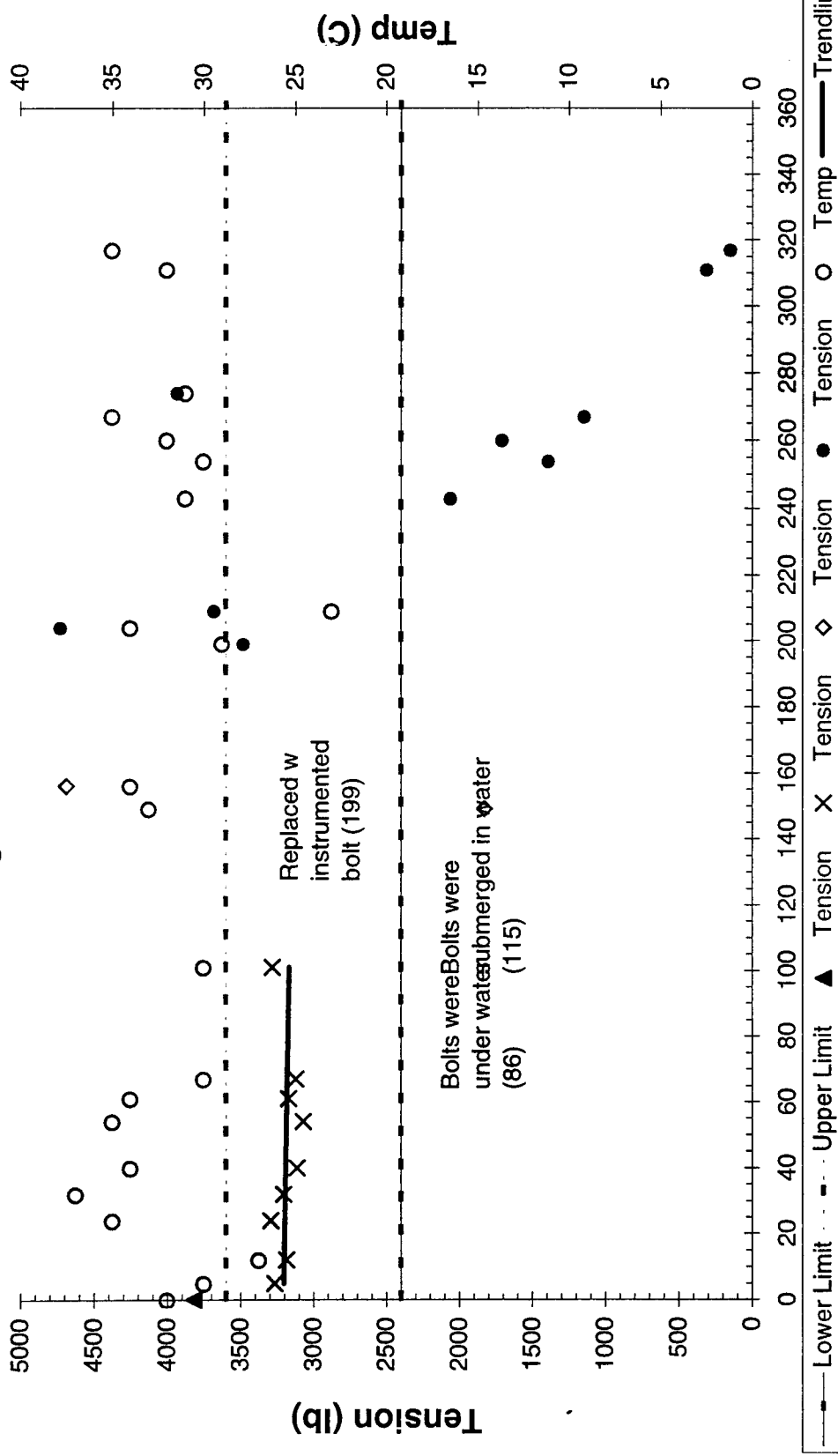


Figure 48 Tension vs Time, Martin County Sign, Bolt with Flat Washers

TEMPERATURE TESTS

In some cases it appeared that there was some correlation between the tension readings and the temperature readings. The tension in the bolt goes up or down with the temperature. In particular, this happened for the Sebastian sign bolts both with spring washers (Figures 41); for the First Brevard sign bolts both with and without spring washers (Figures 36 and 37); for the 2nd Brevard sign bolts both with and without spring washers (Figures 33 and 34); and, for the Orlando sign bolt with spring washers (Figure 30). It must be noted, though, that the temperature readings, measured on the surface of the bolt, were indicative of the ambient temperature, and that the temperature of the bolt core was impossible to record in the field.

There were some concerns that the strain gages or the adhesive between the gage and the bolt could be affected by the temperature variations despite the manufacturer assurances to the contrary. Consequently, temperature tests were performed to determine the temperature effects, if any, on the strain gage readings. Several temperature tests were performed on bolts when they were returned from the field.

The procedure for the temperature tests was as follows:

- The untensioned bolts were placed into an Equatherm Oven manufactured by Curtin Matheson Scientific Inc. The bolts were connected to a P-3500 strain indicator to record the strain as the temperature was increased. An Acu-rite oven thermometer measured the temperature of the bolt.
- The temperature was increased from an initial ambient bolt temperature of around 24 °C to a maximum temperature of above 80 °C. The strains were measured for temperature increments of around 10 °C. The strain readings were also taken at similar decrements back to the ambient temperature of the bolt.

The results for the tests performed on the Orlando long bolt are shown below. The bolt was tested in three different settings. Figure 49 shows the result of the temperature test for the stand alone bolt, untensioned. Figure 50 shows the result of the temperature test for the bolt installed and tensioned on an aluminum fixture with spring washers. Figure 51 shows the result of the temperature test for the bolt installed and tensioned on an aluminum fixture with flat washers. In

all the tests, it can be seen that the variation in strain is small, consistent with the expected thermal expansion of the steel bolt for this range of temperature. It was then concluded that the strain gages were not adversely affected by the expected temperature changes, and that the bolts could be used as intended in the field.

However, the results of the test do show that the slope of the strain-temperature curve varied for each test. This is to be expected, since the aluminum fixture, the galvanized steel flat washers, the spring washers, and the bolt itself are made of different alloys with different coefficient of thermal expansions. The interactions between the different elements of the connection result therefore in a different rate of thermal expansion or contraction, which may explain the variation of tension with the temperature.

Consequently, the observed variation in tension with the temperature cannot be attributed to the strain gages. The probable explanation is that the sign structures themselves expand or contract non uniformly when subjected to the action of the sun. One face of the posts might be warmer than the other, or one post might be in the shadows of trees while the other is fully exposed to the sun. The differential expansion and/or contraction of the sign might induce additional forces on the break-away connections. These in turn will result in changes in tension of the bolts.

These changes were also documented over a one day period by taking measurements of the same bolt at different times the same day. See readings for days 138 and 147 of the First Brevard sign in Tables 10 and 11; for days 196 and 205 of the 2nd Brevard sign in Tables 8 and 9; for days 196 and 205 of the Orlando sign in Table 6; for days 209 and 243 of the Indian River sign in Tables 14 and 15. Depending on the sign sun exposure and location of the bolt, the changes in tension during the day can be large or small. That will also explain in part the better performance of the spring washers. By design, the spring washers can accommodate these changes in tension and bring back the tension in the allowable range. On the contrary, after several of these temperature cycles, the bolts with flat washers might tend to permanently loosen.

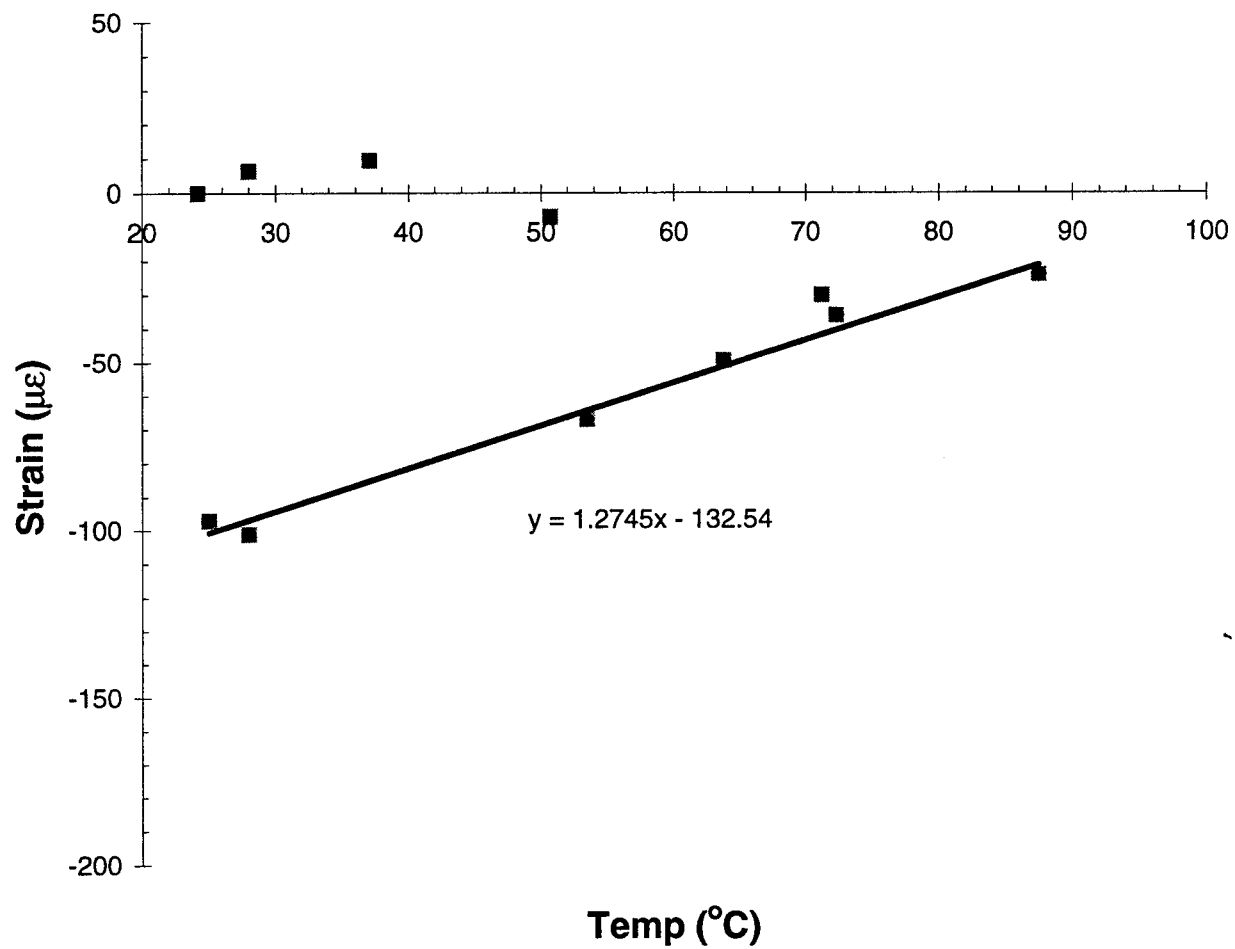


Figure 49: Strain vs Temperature, Orlando Sign, Long Bolt Untensioned, 5/13/99

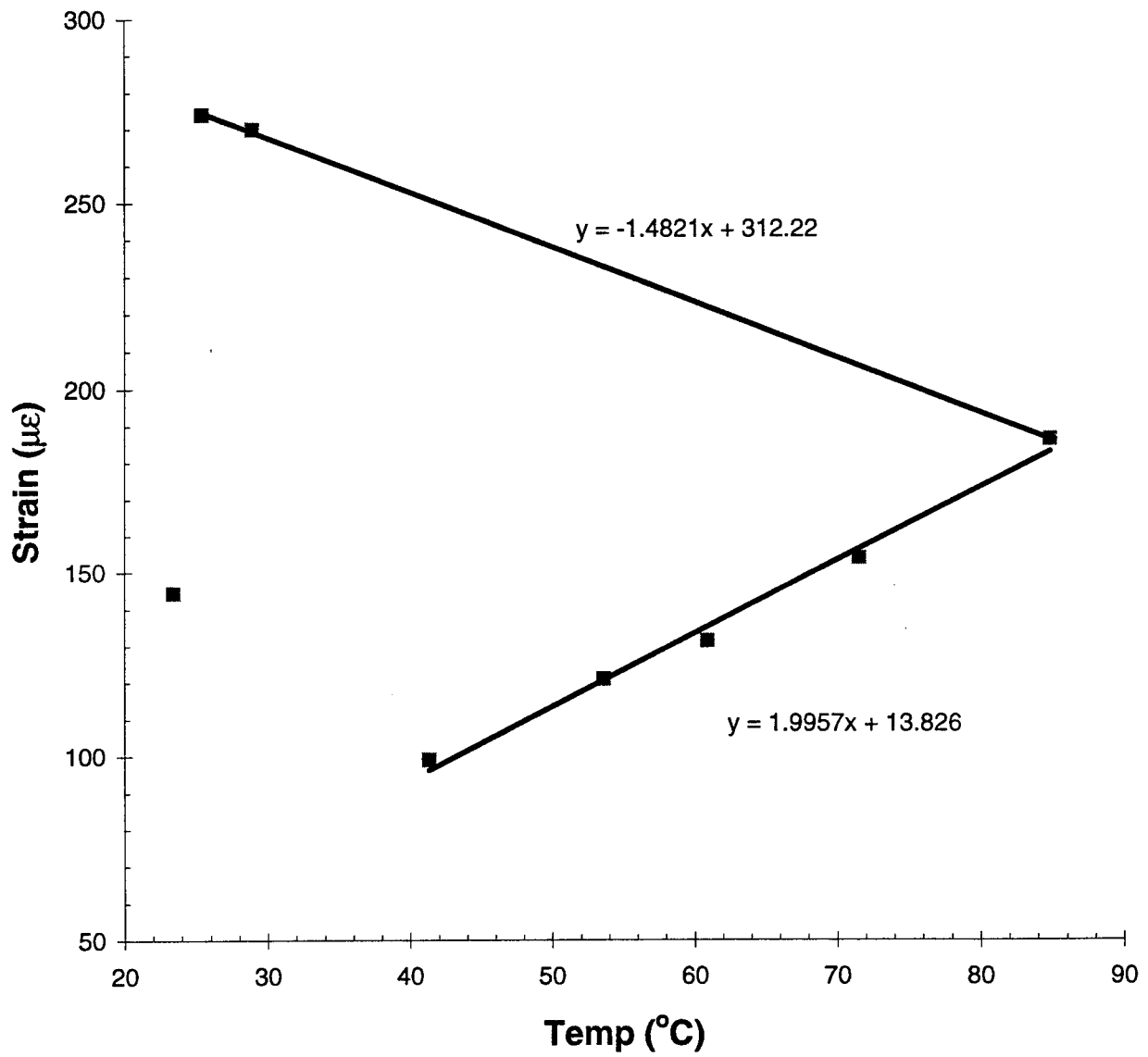


Figure 50: Strain vs Temperature
Orlando Sign, Bolt w/ Spring Washers, Tensioned, 5/6/99

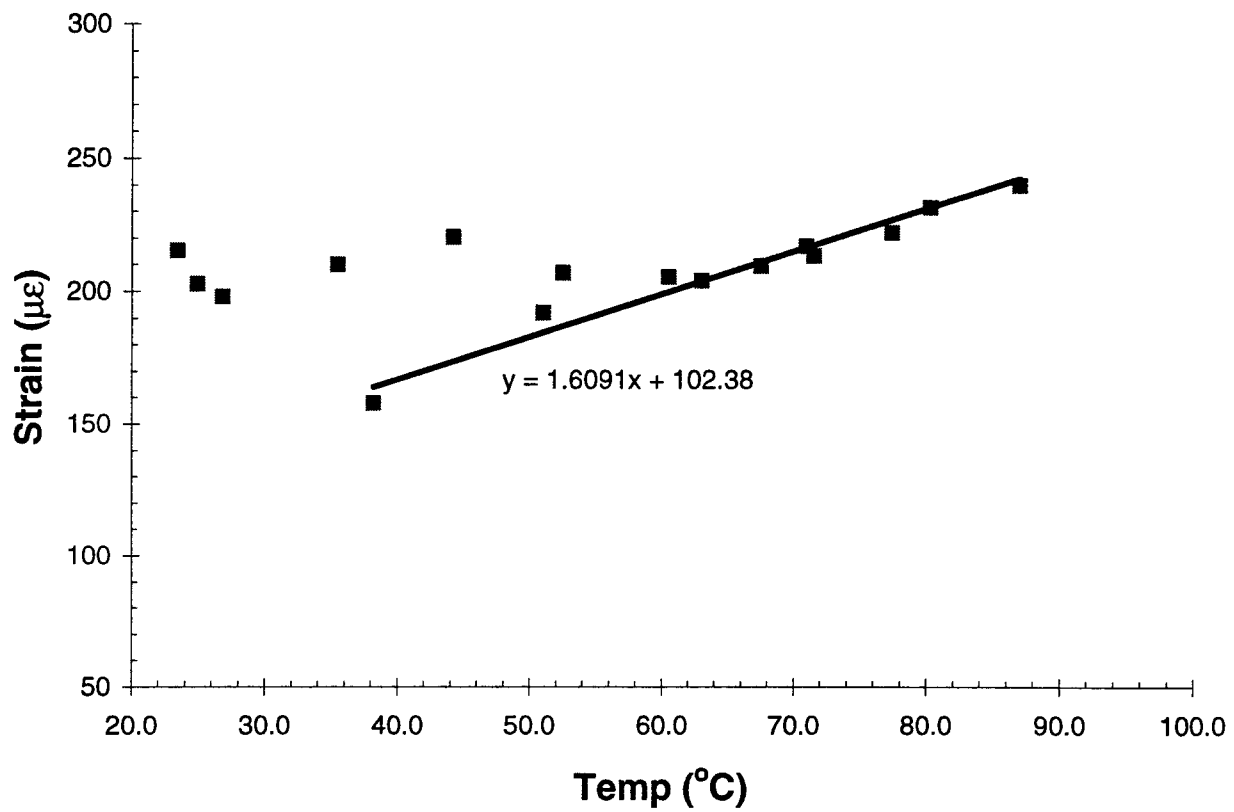


Figure 51: Strain vs Temperature
Orlando Sign, Long Bolt w/ Flat Washers, Tensioned, 5/7/99

DISCUSSION

Tension in the bolts of seven highway signs were monitored over a period of a year, from May 1998 to the present. Seven bolts were equipped with conventional flat washers, while the other seven were installed with Belleville spring washers. However, it was impossible to achieve a continuous record of measurements for each of the 14 bolts monitored. Most of the strain gages had to be replaced at one point or another after being damaged accidentally by the weather, flooding, grass mowers, or other causes. Therefore it is somewhat difficult to show definite long term trends in the behavior of the bolts. However, there were clear differences between the two sets of specimens. They are summarized below.

Bolts with Spring Washers

Long term behavior

The bolts equipped with spring washers appeared to have a better, more predictable behavior. They were able to maintain the tensions within the acceptable range for five out of seven signs.

The Orlando sign is the only sign that was never damaged, and therefore was never re-torqued. It is the only sign for which we have a single continuous record of measurements. Throughout the initial 10 month monitoring period, tension readings were all within the acceptable range. Only at the end of the monitoring, during the spring of 1999, the readings went below the allowable range, probably because of a defective gage.

The Indian River and Brevard (2) bolts with spring washers were able to hold the tension within the acceptable range for approximately 200 days after they were torqued. Lamentably, both bolts had to be re-installed in February 1999. Since then, the tension readings kept within the acceptable range.

The Tampa bolt with spring washers was able to hold the tension within the acceptable range for 112 days after it was first installed. Lamentably, the left wire was cut on October 1998 and the bolt was not re-installed until February 1, 1999. On February 8, 1999, the initial readings were too low so the bolt was re-torqued using a new spring washer stack. After an initial peak, the tension readings have kept within the acceptable range to date.

The Brevard (1) bolt with spring washers were able to hold the tensions in the acceptable range for approximately 85 days, after the initial installation. However, the bolt had to be re-installed on November 20, 1998 and the tension readings were initially slightly above the upper limit of 3600 lb and then stayed in the allowable range. The temperature readings for this particular series seemed to follow the trend of the bolt tensions.

The Martin and Sebastian bolts with spring washers had several problems with their strain gages throughout the testing program, so no definite trend could be observed.

The results of the monitoring of the bolts showed that the spring washers can maintain the tension in the bolts for extended periods of time. The Orlando sign is a prime example. The bolt has never been re-torqued since it was installed on May 16, 1998 and yet, the tension was maintained within the acceptable range for most of the experiment. It should be noted that the Orlando sign is in a high-traffic area and this fact supports the ability of the spring washers to maintain tensions more efficiently than regular flat washers do.

The Indian River results also show that the spring washers can maintain the tension in a bolt even if the bolt is not properly aligned. From June 17, 1998 to January 18, 1999, the left gage registered negative strains, as a result of a big eccentricity in the bolt. Nevertheless, the spring washers were able to maintain the tension for a majority of the time.

Finally, and very importantly, the connection with spring washers displayed outstanding behavior during a car accident, as described above in the section on the results of the Sebastian Inlet bolt.

Galvanized vs. stainless washers

At each sign location, three bolts were assigned galvanized washers, and one bolt was assigned stainless washers. To date, no significant differences were observed between the two types of washers, in term of behavior, degradation and rust. Rust was observed in both cases. However it seems to be more related to the fact that the washers come prepackaged in a plastic wrap that traps the humidity. In all cases, the rust appeared on the edges of the washers.

Installation procedure

The tension in the bolts depends on the deflection of the spring washers. Consequently, the investigators have proposed an installation procedure based on measuring the deflection with filler gages. The procedure is described with details in the Phase I report [1]. Over the course of the study, a total of 21 installations of instrumented bolts with spring washers were performed with this method. Table 18 summarizes the results of these installations. For each of the seven signs, the different installations are listed, with the corresponding dates and the values of the tension measurements for the two readings following each installation. We are including the second reading in the table, because we observed that sometimes, although the first readings indicated a value outside of the allowable tension range, after a short initial period of adjustment, the second and subsequent readings fell between the range.

It can be seen that out of 21 cases, 81% (or 17 cases) were successful installations, and only 19% (or 4 cases) were unsuccessful. Successful means that the tension in the bolt was in the allowable range. This is a fairly high rate of success, specially compared to the 32% rate of success for the traditional torquing method, as described in the next section. However, we feel that the method could be improved upon by designing a special instrument to measure the deflections. Also, it was observed that lubrication of the connection prior to installation improves the chances of success.

	Reading #	1	2
<i>Sign</i>	<i>Date</i>	(lb.)	(lb.)
<i>Tampa</i>	5/18/98	2178	1806
	6/10/98	1877	1883
	2/1/99	2755	
	2/8/99	4093	3024
<i>Orlando</i>	5/16/98	3382	3651
<i>Brevard (2)</i>	5/16/98	2787	3299
	2/12/99	3333	2960
<i>Brevard (1)</i>	7/14/98	3697	2956
	11/20/98	3880	3836
<i>Sebastian Inlet</i>	5/15/98	2671	2505
	11/11/98	3148	-298
	12/4/98	2654	
	1/22/99	2400	
	1/29/99	3039	
	2/5/99	2846	2555
<i>Indian River</i>	5/15/98	2018	1787
	6/17/98	3434	2684
	2/5/99	3341	2869
<i>Martin County</i>	5/15/98	3068	3491
	11/11/98	3530	
	12/4/98	2678	4109

Table 18: Tension in Bolts with Spring Washers

Maintenance

The maintenance procedure should be the same than for the traditional flat washer connections. It is emphasized that a better installation and latter performance will be achieved if the bolt and washers are initially lubricated. In addition, special care should be given to the filler gages used for installation. They should be conveniently oiled and kept without corrosion, to ensure proper measurement of the spring washer deflections. The bolts and stacks of washers should be replaced periodically in accordance with manufacturer prescriptions, and FDOT maintenance schedules [1].

Bolt with Flat Washers

Long term behavior

The tension readings in the bolts with flat washers generally were not within the acceptable range. In four out of seven cases, the tensions in the bolt decreased over time. In four out of seven cases, in spite of being installed with the proper torque according to FDOT specifications, the bolts remained under-tensioned. In one case the bolt was over-tensioned despite being torqued to the proper FDOT specifications.

The Orlando sign registered tensions below the lower bound with a decreasing trend since it was first installed in May 16, 1998. The bolt has been re-torqued six times and four out of these five times, the bolt was under-tensioned. Despite using a new torque wrench, two out of the three times it was used, the bolt still remained under-tensioned. The left gage has almost always registered a negative strain since June 10, 1998. This resulted in a big eccentricity in the bolt. One possible cause for this result is that the different connection components are not properly aligned.

The Indian River bolt had only one tension reading within the acceptable range. In spite of being torqued to the proper torques according to FDOT specifications, the bolt still remained under-tensioned.

The Brevard (2) bolt also had only a few tension readings within the acceptable range. In spite of being torqued to the proper torques according to FDOT specifications, the bolt still remained under-tensioned.

The Tampa sign registered values in the allowable range with peaks above the range, and the tension readings fluctuated a lot.

The Martin sign was able to maintain the tension within the range for 101 days. After it was replaced on December 4, 1998, the tension fluctuated severely.

The Sebastian sign registered an increasing trend. The bolt was re-installed on November 11, 1998 and the tension readings were above the upper bound of 3600 lb. The bolt was again re-

installed on December 4, 1998 and since then, the tension has only been in the acceptable range once.

The Brevard (1) sign has never been re-torqued since it was installed in July 14, 1998. The results have always been below the allowable values.

The results of monitoring the bolts show that the flat washers cannot maintain the tension over an extended period of time. The Brevard (1) sign is a clear indication of this trend. Another observation is that the tension fluctuated more with the flat washers than the spring washers.

Installation procedure

The results also show that the current installation technique is faulty. In four out of seven cases, the bolts remained under-tensioned in spite of being installed with the proper torque according to FDOT specifications. In one case the bolt was over-tensioned despite being torqued to the proper FDOT specifications.

In this case, the tension in the bolts depends on the magnitude of the torque applied. The method of installation is described with detail in the FDOT manual [2]. However, we were surprised to find that the different FDOT jurisdictions are not in agreement over the value of torque to be used. Table 1 in the first part of this report shows that one jurisdiction at least (Orlando) uses a value of torque of 36 ft-lb, different from the 43 ft-lb used by the other FDOT offices.

Over the course of the study, a total of 31 installations of instrumented bolts with flat washers were performed with the conventional method. Table 19 summarizes the results of these installations. For each of the seven signs, the different installations are listed, with the corresponding dates and the values of the tension measurements for the two readings following each installation. We are including the second reading in the table, because we observed that sometimes, although the first readings indicated a value outside of the allowable tension range, after a short initial period of adjustment, the second and subsequent readings will fall between the range.

It can be seen that out of 11 cases, only 32% (or 10 cases) were successful installations, and 68% (or 4 cases) were unsuccessful. Successful means that the tension in the bolt was in the

allowable range. This is a fairly high rate of failure, specially compared to the 81% rate of success for the new torquing method, as described above. It was observed that lubrication of the connection prior to installation improves the chances of success. However, from our experience in the field with the FDOT crews, consistent lubrication of the connections does not seem a realistic option.

	Reading #	1	2
<i>Sign</i>	<i>Date</i>	(lb.)	(lb.)
<i>Tampa</i>	5/18/98	2915	3613
	6/10/98	4273	2959
	2/1/99	2414	
	2/8/99	2159	1787
<i>Orlando</i>	5/16/98	2601	9705
	6/10/98	2671	1992
	10/23/98	2140	
	11/4/98	1409	1243
	12/2/98	2404	1987
	2/1/99	2208	
	2/8/99	1705	
	2/15/99	1098	
	2/22/99	2674	
<i>Brevard (2)</i>	5/16/98	3523	5714
	6/1/98	6009	
	6/10/98	4177	1557
	11/13/98	3316	5291
	1/25/99	1165	777
	2/8/99	1547	1040
<i>Brevard (1)</i>	7/14/98	2651	2529
<i>Sebastian Inlet</i>	5/15/98	4215	3568
	12/4/98	3774	3780
	2/5/99	4300	3449
<i>Indian River</i>	5/15/98	2255	5810
	6/25/98	1672	1877
	11/6/98	6455	
	11/11/98	1239	
	12/9/98	970	672
	2/5/99	2199	2124
<i>Martin County</i>	5/15/98	3818	3267
	12/4/98	3476	4722

Table 19: Tension in Bolts with Flat Washers

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

A new method is proposed to measure and maintain the tension in the bolts of break-away slip base connections. The method is fairly simple to implement, and it is based on the utilization of Belleville spring washers. For each different bolt diameter and associated load range, a combination of spring washers is recommended. The stacks of spring washers, which come pre-wrapped, are installed on the bolt just as any ordinary washers, and the bolts are torqued with any kind of torque wrench. According to the method, a block of filler gages measures the deflection of the stack of spring washers which is proportional to the tension in the bolt. For each desired value of tension, there is a corresponding value of deflection. The main advantage of this technique is that it eliminates the uncertainties associated with torque measurements, and it provides a more reliable way to estimate the tension of the bolt.

Seven signs were selected along Central and South Florida highways. At each sign, one of the posts was equipped with bolts with spring washers, while the other post remained connected with bolts with conventional flat washers. At each sign, one of the bolts with spring washers and one of the bolts with flat washers were instrumented with strain gages, and the variations of tension in these bolts were monitored over a period of several months.

The following conclusions were obtained based on the results of the field monitoring.

1. Over the long term, bolts installed with spring washers appear to maintain the tension in the bolt. No instances of consistent bolt loosening below the allowable range of tensions were observed, even in high traffic areas like Orlando.
2. On the contrary, several bolts installed with flat washers exhibited a downward trend in the bolt tension.
3. The proposed installation procedure based on measuring deflections of the spring washers appears to be more successful than the conventional method based on measuring the torque. 81% of the bolts installed with spring washers had their initial tension in the allowable range, as opposed to only 32% of the bolts installed with flat washers.

4. The effectiveness of the break-away connection with spring washers was demonstrated during a car accident. A car hit a sign post equipped with spring washers, near the Sebastian Inlet. The break-away functioned perfectly and the post separated from the base.
5. Over the monitoring period, no significant advantage was observed regarding the use of stainless washers. Minor corrosion was observed for both the stainless and galvanized washers, and it appears to be due to the fact that the plastic wrapping of the stack of washers traps some humidity. The solution could be to slash the wrapping after installation.

Recommendations

Based on the results of the field monitoring, which confirm the results of the laboratory tests from the phase I of the project, spring washers appear to be a good alternative to the use of conventional flat washers, for break-away connections. The accurate measurement of the deflection of the stack of spring washers remains a critical issue. Filler gages can be used with a reasonable rate of success, as shown during this testing program, although the investigators feel that the FDOT crews would be reluctant to use the method as is. As a compromise, the bolts could still be installed with spring washers, to ensure that no loosening occurs, but they could be torqued with the conventional method.

To take full advantage of the proposed solution for break-away connections, we strongly recommend that a special measurement device be developed to specifically measure the deflection of the stack of spring washers. Such a device would significantly improve the efficiency of the method.

REFERENCES

1. FDOT, Ground Mounted Single And Multi-Pos Sign Inspection Manual, Florida Department of Transportation, November 1994.
2. Pinelli, Jean-Paul, Subramanian, Chelakara. *Final Report, Study of Break-Away Sign Connections, State Job No. 99700-3344-119, Contract No. BA521, WPI No. 0510777, March 18, 1998*